cal dynamics rather than a smooth behavior.) A finite number of mirrors suffices to describe the full dynamics, one for each choice of the DoD. The (x,y) coordinates of the particle when passing through a fixed, imaginary plane simulate the dotted sequence $x.y$. To define the computation, the particle starts in input location $\bar{0}.y_0$, where y_0 is the finite input string; the output is defined in finite terms as well. Although Moore proved the Turing machine simulation by such a system, the advice can also be encoded in a uniform manner by the characterizations of the mirrors. For example, the concatenation of all advice can be the characterization of the first mirror that is being hit, continuing with mirrors of finite characterizations, simulating the finite DoE. When the halting state of the Turing machine is reached, the particle hits a mirror that throws it to a particular observable x coordinate, where all points are fixed. The output is defined as the y coordinate when this observable x_0 is reached. Forcing the input and output to reside in observable areas (using, for example, Cantor set encoding) makes the system realizable. Another possible realization may be based on the recent optical realization of the Baker's map (*22*).

Although it may have seemed that infinite precision was required to fully describe the associated computation, this is not the case, because linear precision suffices for analog computation models (9). That is, if one is interested in computing up to time q, both the mirror system and the location of the particle bouncing there are not required to be described (or measured) with more than q bits. This property is in accordance with the sensitivity of chaotic systems to exponentially precise initial conditions (here, the mirror system), which suggests that the analog shift map is indeed a natural model of chaotic (idealized) physical dynamics.

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Dating and Context of Three Middle Stone Age Sites with Bone Points in the Upper Semliki Valley, Zaire

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The extent to which the earliest anatomically modern humans in Africa exhibited behavioral and cognitive traits typical of *Homo sapiens sapiens* is controversial. In eastern Zaire, archaeological sites with bone points have yielded dates older than 89^{+22}_{-15} thousand years ago by several techniques. These include electron spin resonance, thermoluminescence, optically stimulated luminescence, uranium series, and amino acid racemization. Faunal and stratigraphic data are consistent with this age.

During the late middle to early upper Pleistocene in Africa, anatomically modern humans (*Homo sapiens sapiens*) replaced archaic *Homo sapiens*. Middle Stone Age (MSA) archaeological materials provide information on human behavior during this transition. In tropical Africa, MSA artifacts with associated fauna and chronometric ages are known from only a few well-excavated rock-shelter and stratified open-air contexts (*1, 2*). In this report, we describe the geological context and dating of three MSA sites with bone points in eastern Zaire.

The Semliki Valley (Fig. 1) runs north-northeast along the floor of the western (Albertine) branch of Africa's modern rift valley system, from Lake Rutanzige (formerly known as Lake Edward) to Lake Mutanzige (formerly Lake Albert) (*3*). Sites along the northern shore of Lake Rutanzige and the Upper Semliki Valley range from Pliocene to Holocene age (*4*).

The current savanna-woodland vegetation and fauna of the Upper Semliki Valley are a response to rain-shadow microclimatic effects of the western rift wall and to the porous, base-rich ash of early Holocene age that blankets the local landscape (*5*). These factors may have been quite different during the Pliocene and Pleistocene. In contrast to the eastern (Gregory) rift, exposures of Plio-Pleistocene and Pleistocene sediments in the Semliki are very limited. The chronology of the sequence before this study was based largely on faunal comparisons and lithostratigraphy.

Early archaeological work (*4, 6*) focused primarily on the lake-shore site of Ishango, with its small barbed bone and ivory points, fish and mammal bones, fragmentary human remains, quartz tools, and an engraved bone haft that may indicate an understanding of multiplication by 2's. Ishango and other archaeological and paleontological occurrences (*7*) attracted renewed multidisciplinary research in the Upper Semliki (*8–12*) between 1982 and 1990.

New materials (Table 1), especially ostrich eggshell, were recovered for dating from the original Ishango site (Ishango 11) and from a comparable-age site 2 km downstream (Ishango 14) (*13*). Together with a restudy of the original fauna by Peters (*14*), these suggested that the *niveau fossilifère* *principal* (principal fossiliferous level) at Ishango dated to as much as 25,000 years before present (B.P.). Human remains (*15*) and double-row barbed bone points from this level are now attributed to the late Pleistocene rather than to the Holocene (*16*). Microlithic cores were also recovered from excavations in 1985 and 1986, linking the early Ishango levels to the Later Stone Age (LSA).

Further downstream, at Katanda (Fig. 1), we recovered at three localities barbed and unbarbed bone points from much older contexts in association with stone tool industries characterized by discoidal core preparation (*17*). Located in the >40-m-high Katanda cliffs along the east bank of the Semliki River, these sites were designated, from south to north, Katanda 2 (Kt2), Katanda 9 (Kt9), and Katanda 16 (Kt16) (Fig. 2).

At each Katanda site, the stratigraphic sequence consists of four sedimentary units (Fig. 3). From lowest to highest, these are Lusso beds, Semliki beds, Katanda beds, and the capping Katwe volcanic ash.

1) Lusso beds are lacustrine clay and silt with occasional ironstone horizons. At Katanda, fossils of mollusks (*18*), fish (*19*), and mammals, including *Elephas recki* (stage II/III), *Notochoerus euilus*, and *Hexaprotodon* cf. *imagunculus*, were recovered in the ironstones (*20*). These imply a late Pliocene to earliest Pleistocene age for the Lusso beds at Katanda.

2) The alluvial Semliki beds include silt, sand, and occasional fine gravel in multiple, fining upward depositional sets (*21*). Dating the Semliki beds is problematic. Archaeological remains are associated with sandy, oxidized, variably cemented horizons (*22*) that apparently provided stable land surfaces after lateral migration of the main channel. The lowest such horizon in the cliff at Kt2 is 29 m above the river. It yielded undiagnostic flake and pebble tools, without bifaces or discoidal cores, comparable to lower Pleistocene assemblages from east Africa (Oldowan). Fauna included *E. recki* (stage IV) and *Alcephalus* cf. *lichtensteini*. Another archaeological horizon 2 m higher yielded smaller flakes and pebble tools, with biface fragments and poorly preserved faunal remains. By implication, the Semliki beds are middle Pleistocene or older, as the youngest stratigraphically secure published occurrence of *E. recki recki* to date is from bed IV at Olduvai (0.62 to 0.83 million years old) (*23*). The Semliki beds are capped by a major unconformity and complex carbonate paleosol (the ASB paleosol). This distinctive marker horizon signals a long period of landscape stability under persistently semiarid climates.

3) The Katanda beds (*24*) are exposed along at least 15 km of the modern Semliki Valley from Ishango to Kasaka. The base of the unit rests unconformably on the ASB paleosol, whereas the top is marked by the contact with the Katwe ash. The three archaeological horizons with barbed bone points, MSA artifacts, and faunal remains that are the focus of this report are all at or near the base of the Katanda beds.

At the base of the Katanda beds, well-sorted sandy alluvial facies with crossbedding primarily represent lateral fills along a floodplain margin and the valleys of ephem-

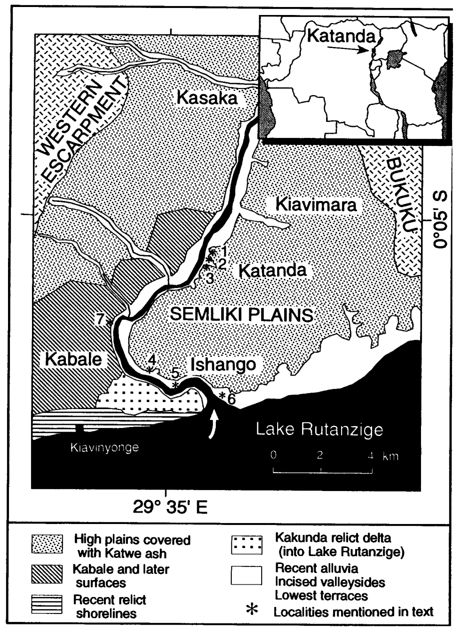

Fig. 1. Upper Semliki region with sites mentioned in the text: (1) Katanda 16, (2) Katanda 9, (3) Katanda 2, (4) Kabale 1, (5) Ishango 14, (6) Ishango 11, (7) Kabale 7.

Table 1. Upper Semliki archaeological sites. The sites are listed in geographical order, moving south to north. Names in quotes refer to the original level designations used by de Heinzelin. The ^{14}C ages are all calibrated and are followed in parentheses by the ^{14}C laboratory and sample numbers.

Site	Level, industry	Age range
Ishango 11	"Zone post emersion," LSA to Neolithic	1680 ± 80, 2200 ± 80 3170 ± 90, 3140 ± 80 (CAMS 3235–3237, 3239)* (Beta 54933–35, 37)*
	"Tufacés," Ishangian, early LSA	20,155 ± 245 (SI-7062)†
	"Niveau fossilifère principal," Ishangian, early LSA	19,780 ± 240 (SI-7065)† 19,920 ± 450 (Beta-22407)† 21,000 ± 500 (W-283)† 23,760 ± 385 (SI-7064)† 25,290 ± 350 (AA-3300)‡
Ishango 14	291 to 301 cm below surface datum, early LSA	16,500 ± 480 (Beta 22050)§ 20,200 ± 530 (Beta 22051)† 22,150 ± 500 (Beta 22052)†
Kabale 1	Katwe ash below LSA, Neolithic	6890 ± 75 (SI-7066)*
Katanda 2	Ravine fill below site	590 ± 65 (Beta33188/ETH 5872)*
	MSA sands (two horizons)	See Katanda 9
	MSA above ASB paleosol	See Katanda 9
	ESA (bifaces)	?
	ESA (Oldowan) two horizons	Early middle Pleistocene (*E. recki recki*)
Katanda 9	Sands directly above MSA	82,000 ± 8000‖
	MSA above ASB paleosol	89,000 ± 22,000¶ (EU) 155,000 ± 38,000 (LU) 139,700 ± 4110# 173,810 ± 800
Katanda 16	MSA above ASB paleosol	See Katanda 9
Kasaka 2	Gravels with Acheulean	?

*^{14}C on charcoal. †^{14}C on mollusk shell (note: modern shell dated to 1650 to 3000 years B.P.). ‡^{14}C on ostrich eggshell. §^{14}C on crab carapace (claws). ‖TL on sands. ¶Average ESR age on tooth enamel, $n = 6$; EU and LU response. #Mass spectroscopic U-series ages on dentine from two different teeth.

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eral tributary streams. Middle and upper parts of the Katanda beds are dominated by colluvial facies with eolian components, which signal a significantly lower elevation of the coeval Semliki channel (*25*).

As a whole, the Katanda beds represent a considerable time span. At Kt16, we distinguished three separate pedogenic carbonate paleosols, each recording a $CaCO_3$-cemented, relict B-horizon suite. Each suite is separated by an erosional unconformity and varies laterally. In addition, a sharply bounded calcrete records a relict high level of ground water that postdates deposition of the sediments. The youngest suite underlies the Katwe ash cover and is thus older than 7000 years B.P. It may correlate to the hyperarid interval of the last glacial maximum at ~18 thousand years ago (ka) recorded by low levels of Lake Tanganyika and other lakes (*26*). On the other hand, the oldest relict carbonate zone above the ASB paleosol at Kt16 incorporates multiple generations of carbonate on the ped faces, implying several episodes of carbonate cementation over peds rich in illuvial clay and oxidation zones and signifying greater age (*27*). A much earlier late Pleistocene age for the Katanda MSA horizons underlying all three carbonate suites would be consistent with these data (*28*).

4) A carbonate-rich volcanic ash buries much of the Upper Semliki landscape. Its thickness is typically 2 to 3 m but increases to as much as 15 m where it fills relict gullies. The presumed source is the nearby Katwe volcanic field in Uganda. Traces of comparable volcanic minerals, for example, perovskite, can be found throughout the Katanda beds. Most of this material, however, apparently relates to a single, major eruptive phase, informally called the Katwe Bulk. A charcoal sample from 0.6 m below the surface of unaltered massive ash yielded a radiocarbon date of 6890 ± 75 years B.P. (Table 1). Soils on the surface of Katwe ash are andisols and weakly developed mollisols compatible with this age. Iron Age and LSA archaeological horizons have been recovered on and below the modern surface (*10, 15, 29*).

At Kt2, a major excavation of some 108 m² was carried out from 1986 to 1990. Seven archaeological horizons were encountered, of which five were subject to at least 10 to 20 m² of areal excavation. An MSA assemblage with an associated unbarbed bone point was excavated in an undisturbed context, immediately above and in contact with the ASB paleosol but not cemented into it. This and two additional closely superimposed MSA horizons with poorly preserved fauna were overlain in turn by 1.5 to 2 m of colluvial sands with derived calcrete gravels lacking artifacts and by 1 to 2 m of Katwe ashes.

Katanda 9 is located 120 m to the north of Kt2, across a deep ravine. Here, immediately above the ASB paleosol, we excavated a major MSA concentration in an undisturbed context, below ~8 m of Katanda beds and of Katwe ash. This dense concentration of lithic artifacts, bone points, and faunal remains of fish and mammals was sharply bounded on three sides and measured about 5.8 m by 7.2 m (*30*).

At Kt16, about 350 m north of Kt9, 5 m of undisturbed sands and silts overlay a horizon of MSA artifacts and the ASB paleosol. Although this occupation was considerably less dense and lacked the sharp boundaries seen at Kt9, it did include grindstones and a barbed bone point.

These three sites represent early evidence of standardized, carefully shaped bone tools in association with MSA industries. Initially, it was assumed that the presence of formal bone tools might indicate a relatively recent age for the MSA at Katanda, closer to 40 ka (*31*). The closest dated MSA occurrences are at Mumba (Tanzania) (*2*) in association with uranium decay (U-series) and amino acid racemization (AAR) dates of 130 to ~40 ka (*32, 33*). By contrast, early

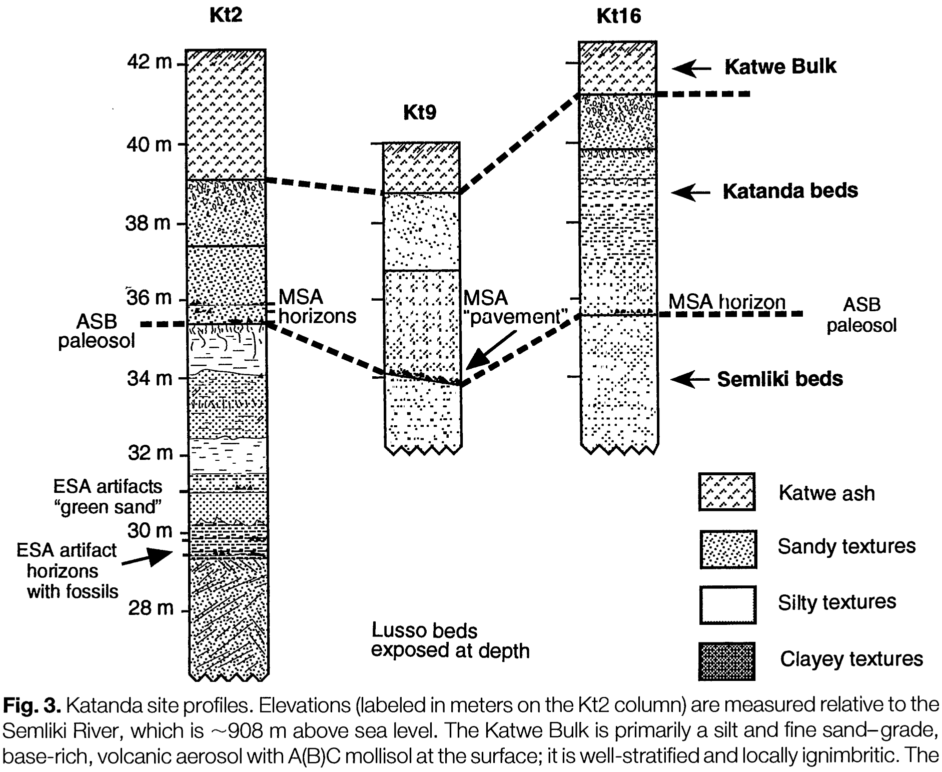

Fig. 3. Katanda site profiles. Elevations (labeled in meters on the Kt2 column) are measured relative to the Semliki River, which is ~908 m above sea level. The Katwe Bulk is primarily a silt and fine sand–grade, base-rich, volcanic aerosol with A(B)C mollisol at the surface; it is well-stratified and locally ignimbritic. The upper Katanda beds are primarily colluvial sands with locally derived pebble and gravel-grade clasts as well as alluvial components. The coeval river level then was probably less than 20 m above current levels, not correcting for possible tectonic changes. The lower Katanda beds are valley-floor colluvia and alluvia, primarily sandy but with important silty components at Kt16. The coeval river level then was about 33 m above present levels. Kt2 is primarily medium and coarse sands of the valley margin. Kt9 is primarily medium and fine sands, with thin coarse sand lenses near the coeval channel margin. Kt16 is diverse, with both finer and coarser facies within the channel axis of a probable ephemeral tributary. The primary MSA artifacts and fossils occur on top of the ASB paleosol, but not cemented into it, and are thus younger than the soil development. The preservation of relatively fragile bones argues for low-energy sedimentation. The Semliki beds record deposition along the axis of a large, northbound river. Near Katanda, the Semliki beds are assorted clayey silts and medium- to fine-grade sands with many minor carbonate-cemented horizons. At depth, crossbedded sands are conspicuous. The ASB paleosol at the surface records a long-lasting land surface. Early Stone Age artifacts are relatively common on sandy substrates near Katanda. Below the illustrated sections are outcrops of the relatively clayey Lusso beds.

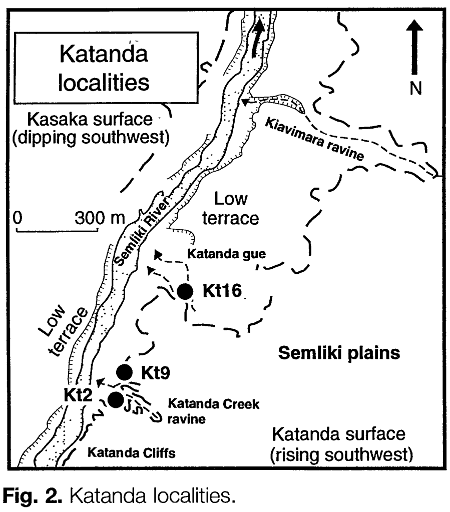

Fig. 2. Katanda localities.

LSA microlithic cores like those from Ishango are dated by radiocarbon at Matupi Cave (Ituri, Zaire) to >40.7 ka (*34*).

The three Katanda MSA sites contained several extant mammalian species not present in the area today (Table 2). Large mammal faunas today include primarily water-dependent species characteristic of open woodland-savanna environments: reduncines (for example, Ugandan kob, Bohor reedbuck, and waterbuck), tragelaphines (for example, bushbuck and, formerly, sitatunga), African buffalo, hippopotamus, three genera of African suids (*Potamochoerus*, *Hylochoerus*, and *Phacochoerus*), and a range of primates and carnivores (*11*). Semiarid grassland species such as the topi, wildebeest, hartebeest, gazelles, impala, zebra, giraffe, and ostrich are absent (*35*). The Katanda MSA faunas, however, include both dry savanna species (zebra, blue wildebeest, and small bastard hartebeest comparable to the blesbok or bontebok) and species present today only in more closed or swampy habitats (sitatunga and clawless otter). The suggested environment is that of a denser gallery forest than at present, fringing a more open savanna grassland than at present, possibly corresponding to a period of cooler, drier climate. Proximity of the Katanda sites to a penecontemporaneous river is suggested both by the numerous fish fossils at all three sites and by the remains of *Aonyx* and crocodile. Fish remains from Kt16 (Table 3) include at least two genera (*Hyperopisus* and *Gymnarchus*) absent at Ishango and previously known only from occurrences in the Lusso beds. Taken as a whole, the faunal remains imply both a different local climate from the present and an age earlier than Ishango.

Table 2. Mammals identified in Katanda MSA horizons (ratio of the number of identifiable skeletal parts to the minimum number of individuals).

Species	Kt2	Kt9	Kt16
Hystrix sp.	1/1		
Aonyx sp.			1/1
medium viverrid			1/1
Loxodonta africana		2/1	
Equus cf. *burchelli*		1/1	
Hippopotamus amphibius	11/1	100/1	22/1
Phacochoerus ethiopicus		5/1	
Potamochoerus porcus	1/1	4/1	
Suidae gen. and sp. indet.	1/1	10/1	
Tragelaphus spekei		2/1	
Redunca cf. *redunca*		1/1	
cf. *Alcelaphus buselaphus*			1/1
Damaliscus cf. *dorcas**		3/1	
Connochaetes taurinus		5/2	
Syncerus caffer	1/1		
Bovidae indet.			
Small medium		19/1	
Large medium	3/1	24/2	2/1
Large	1/1	10/1	

*Blesbok or bontebok, today confined to South Africa.

We dated the Katanda MSA horizons and the overlying sediments by electron spin resonance (ESR) and U-series analyses of teeth and by optically stimulated luminescence (OSL) and thermoluminescence (TL) dating of quartz sands. The dates are consistent with the relatively older late Pleistocene ages suggested by stratigraphy and paleontology. Radiocarbon (^{14}C) dating of bone from Katanda was not attempted after a C/N assay suggested that collagen was not preserved.

Twenty samples of the sands overlying the Kt9 MSA horizon were collected by night for dating by TL and OSL (*36*). Deflocculation, sieving, extensive acid pretreatment with both HCl and HF, and density separations failed to remove all of the adhering microcrystalline impurities from the quartz fraction. Attempts to use the rapidly bleaching signal of quartz for dating by OSL techniques were only partially successful, probably because of the presence of these impurities. The regeneration dose technique with OSL gave a total paleodose of 192 grays (Gy), and the OSL plateau test method gave a total paleodose of 185 Gy. However, neither result was judged reliable because of the anomalous laboratory dose-dependent behavior of the OSL signals.

Finally, we used the standard TL dating technique based on the slowly bleaching signal attributable to quartz because its dosing characteristics were satisfactory. The result was a total paleodose of 170 ± 10 Gy. This result assumes that the solar bleaching of the sediment at deposition lasted at least several hours.

A gamma-ray spectroscopic analysis of the untreated sample material was used to determine the complete radioactivity present. No secular disequilibrium was detected for either the U or Th decay chains. A corresponding radioactivity dose rate of 2.08 ± 0.10 Gy/ka was calculated. This value, combined with the paleodose, gives a TL age of 82 ± 8 ka. The two OSL results suggest that the age may be closer to the upper limit of 90 ka.

Table 3. Fish remains from Kt2, Kt9, and Kt16 (minimum number of individuals).

Genus	Kt2*	Kt9	Kt16
Protopterus		1	3
Polypterus			8
Hyperopisus			1
Gymnarchus			5
Mormyriformes		2	3
Barbus		4	24
Bagrus		2	12
Clarias	9	62	54
Synodontis	1	103	111
Siluriformes		17	
Lates		6	6
Cichlidae		35	53
Perciformes		1	

*Elements were worn and encased in matrix, so they were less identifiable than at other Katanda sites.

Enamel from three teeth of *Hippopotamus amphibius* from the Kt9 assemblage was analyzed by ESR dating (*37*). These teeth, like other MSA faunal remains from Katanda, exhibit mineralization and color similar to that of the bone points and are closely associated with them spatially. The dose associated with absorbed U was high in both the enamel and the dentine (*38*). Therefore, the calculated age does not depend critically on the external dose rate, which was determined only by chemical analysis of samples of enclosing sediment provided by the excavators. Two and three subsamples were obtained from the two larger teeth, respectively, and only one enamel sample was obtained from the third fragment (*39*).

The ESR age of tooth enamel depends on the U uptake history of the tooth. Normally, two limiting models are considered: early uptake (EU), which assumes that the present-day U content of dentine and enamel was acquired soon after burial, and linear uptake (LU), which assumes a constant rate of U uptake since burial. For samples with high internal U content, such as those at the Katanda site, the LU age (t_{LU}) can be up to twice the EU age (t_{EU}). The EU dates always yield the minimum possible tooth ages. The average value of t_{EU} for the Katanda samples (n = 6) is 89 ± 22 ka, whereas t_{LU} = 155 ± 38 ka (*40*). The EU age is in good agreement with the TL age, but we would expect the ESR age to be older because the teeth originated some 50 cm deeper in the Katanda beds relative to the sample used for TL dating. Weathering of bones and teeth in the Katanda faunal sample is also consistent with a considerable lag between initial deposition and burial. Note that although both ESR and TL ages are based on the same physical principles (measurement of trapped charges in crystals), the two sets of data are essentially independent because the external dose rate (the only common factor in TL and ESR dating) contributes <10% of the total dose rate to the teeth.

Recently, McDermott *et al.* (*41*) have used mass-spectroscopic U-series analyses of teeth to show that the EU model best describes U uptake at three Israeli sites. Our own U-series analyses of dentine samples from two of the Katanda teeth yielded apparent ages of 140 ± 4 ka and 174 ± 1 ka (*42*). The apparent agreement between these dates and the average LU ESR ages is fortuitous because U-series ages of teeth must be less than or equal to the ESR ages if there has been postdepositional uptake of U (*43*). These older U-series ages suggest that there has been some loss of U late in the burial history, which would lead to anomalously high $^{230}Th/^{234}U$ ratios and ages. It is difficult to assign a precise age to the ESR data in such a case, but we surmise that the dates are somewhere between the EU and LU estimates and agree with the TL ages on the overlying sediment.

At Katanda, three different chronometric techniques, together with sedimentary and faunal analyses, suggest an age for the MSA horizons and associated bone points of greater than 89^{+22}_{-15} ka (*44*), during a period drier than the present. The appropriate correspondence is with the onset of the last glaciation, an age consistent with new MSA chronologies elsewhere in Africa (*45*).

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3. Today, the Semliki River runs northward, as a source of the Nile; in the Pleistocene, however, drainage directions along this rift segment reversed twice.
4. These deposits and their fossils were first noted by V. E. Fuchs [*Geol. Mag.* **71**, 97 (1930); *ibid.* **72**, 145 (1931)] and were later explored intensively by Lepersonne and de Heinzelin, who established the basic Upper Semliki lithostratigraphic sequence [J. Lepersonne, *Ann. Soc. Géol. Belg.* **72**, 1 (1949); *Ann. Mus. R. Afr. Cent. Sci. Géol.* **67**, 169 (1970); W. Adam and J. Lepersonne, *Ann. Mus. R. Congo Belge Ser. 8° Sci. Géol.* **25** (1959); J. de Heinzelin, *Exploration du Parc National Albert, Mission J. de Heinzelin de Braucourt (1950)*, Fasc. **1** (1955), Fasc. **2** (1957), Fasc. **6** (1961); ____ and J. Verniers, *Mus. R. Afr. Cent. Rapp. Ann. Géol. Minérol. (1985–1986)* (1987), pp. 141–144; J. Verniers and J. de Heinzelin, in (*8*), pp. 17–39]. This sequence was later integrated with the one developed by Bishop for the Ugandan side of the Albertine rift [A. Gauthier, in *Background to Evolution in Africa*, W. W. Bishop and J. D. Clark, Eds. (Univ. of Chicago Press, Chicago, 1967), pp. 73–87; *Ann. Mus. R. Afr. Cent. Sci. Géol.* **67**, 1 (1970)].
5. Modern landscapes along the Upper Semliki Valley are strongly influenced by the extraordinary regional relief along this relatively narrow rift segment. The elevation of Lake Rutanzige is 912 m, compared with 2995 m on the rift wall to the west, 5119 m atop the Ruwenzori massif to the north, and 4507 m atop the tallest of the Virunga volcanoes (Karasimbi) to the south. As a result, modern environments vary rapidly across the upper Semliki region. Heavy rains and persistent cloud-cover make the forested mountaintops some of Africa's most humid landscapes. The rift floor, however, is in a complex rain shadow. Equinoctial precipitation totals are in the subhumid range. The highly porous, carbonate-rich volcanic tuffs covering the Semliki plains give the region an even more semiarid aspect. Savannas with *Acacia sieberiana*, *A. hockii*, and *Euphorbia calycina* cover the plains near Katanda, and closed-canopy forests of up to 14 m in height are found on steep slopes and in ravines along the Semliki channel. J. Sept, in (*8*), pp. 95–121.
6. H. Damas, *Rev. Zool. Bot. Afr.* **33**, 265 (1940); P. H. Greenwood, *Exploration du Parc National Albert, Mission J. de Heinzelin de Braucourt (1950)*, Fasc. **4** (no. 1), 1 (1959); A. T. Hopwood and X. Misonne, *ibid.*, Fasc. **4** (no. 3), 111 (1959); R. Verheyen, *ibid.*, Fasc. **4** (no. 2), 109; F. Twiesselman, *ibid.*, Fasc. **5** (1958); J. de Heinzelin, *Sci. Am.* **206**, 105 (June 1962).
7. During the geological survey in the 1950s, the "Semliki series" yielded "middle Paleolithic" and "lower Paleolithic" industries from Katanda and an Acheulean industry from Kasaka. Three stone artifacts were also recovered from the Lusso beds at Kanyatsi on the lake shore.
8. N. T. Boaz, Ed., *Evolution of Environments and Hominidae in the African Western Rift Valley* (Mem. 1, Virginia Museum of Natural History, Martinsville, VA, 1990).
9. A. S. Brooks and C. C. Smith, *Afr. Archaeol. Rev.* **5**, 67 (1987); J. W. K. Harris *et al.*, *J. Hum. Evol.* **16**, 701 (1987); N. T. Boaz *et al.*, *ibid.* **22**, 505 (1992); Muya wa Bitanko-Kamuanga, in *Aux Origines de l'Afrique Centrale,* R. Lanfranchi and B. Clist, Eds. (Centre International des Civilizations Bantu, Libréville, Gabon, 1991); K. Stewart, *Fishing Sites of North and East Africa in the Late Pleistocene and Holocene* (Cambridge Monographs in African Archaeology 34, BAR International Series 521, British Archaeology Reports, Oxford, 1989); N. T. Boaz, in *Integrative Paths to the Past: Palaeoanthropological Advances in Honor of F. Clark Howell*, R. S. Corrucini and R. L. Ciochan, Eds. (Plenum, New York, 1994), pp. 321–343; J. de Heinzelin, *ibid.*, pp. 313–320. Archaeological materials associated with Lusso-age faunas will not be further discussed in this report.
10. Kanimba Misago, *NSI* **5**, 23 (1989).
11. M. Tappen, thesis, Harvard University (1992).
12. R. Bellomo, *J. Archaeol. Sci.* **20**, 525 (1993); in "Society, Culture, and Technology in Africa," *MASCA Research Papers in Science and Archaeology 11 (suppl.)*, S. T. Childs, Ed., in press.
13. At the time of deposition of the Ishango archaeological sites, and during the accumulation of the Katanda beds, the Semliki River flowed south rather than north; reversal to its present direction may date to the middle Holocene.
14. J. Peters, *Rev. PaleoBiol.* **9** (no. 1), 73 (1990).
15. N. T. Boaz, P. P. Pavlakis, A. S. Brooks, in (*8*), pp. 273–299.
16. Prior to this report, these double-row barbed bone points constituted the earliest records of barbed bone points yet described, antedating the European and Saharan examples by at least 6000 to 10,000 years.
17. J. E. Yellen *et al.*, *Science* **268**, 553 (1995). In the discoidal core technique, the desired or usable flakes are removed alternately and more or less symmetrically from both the upper and lower faces of a flattened stone nucleus of circular, oval, or irregular outline. Each negative flake scar thus serves as a platform from which a subsequent flake may be struck. This technology, which produces roughly triangular flakes of a regular shape and size, was first practiced consistently by makers of Acheulean industries around 500 ka but is particularly characteristic of MSA industries in Africa.
18. P. G. Williamson, in (*8*), pp. 125–139.
19. K. M. Stewart, *ibid.*, pp. 141–162.
20. W. J. Sanders, *ibid.*, pp. 171–189; H. B. S. Cooke, *ibid.*, pp. 197–201; P. P. Pavlakis, *ibid.*, pp. 203–223.
21. These beds record deposition along a great, northward-flowing river.
22. Low-energy, fine-textured facies are often cemented with $CaCO_3$ or, more rarely, with iron sesquioxides.
23. R. L. Hay, in "Establishment of a Geologic Framework for Paleoanthropology," L. F. Laporte, Ed., *Geol. Soc. Amer. Spec. Pap. 242* (1990), pp. 23–38; M. Beden, *Les Faunes Plio-Pleistocènes de la Basse Vallée de l'Omo (Ethiopie). t.2 Les Elephantidés (Mammalia, Proboscidea)* (Centre National de la Recherche Scientifique, Paris, 1987). Revision of the middle Awash stratigraphy is in progress; the dating of *Elephas recki recki* occurrences reported by J. E. Kalb and A. Mebrate [*Am. Philos. Soc. Trans.* **83** (part 1), 1–114 (1993); J. E. Kalb, *Newsl. Stratigr.* **29** (no. 1), 21 (1993)] is unclear.
24. Previously, the Katanda beds were included as the uppermost unit of the Semliki series. More recently, Verniers and de Heinzelin (*6*), referred them to a post-Semliki beds unit: "the High Terrace complex." They are defined here for the first time.
25. The relatively small proto–Semliki River of the Katanda sedimentation ran southward, as identified by analysis of sedimentary structures at Kt9 and Kt16. The upper Katanda beds are probably thus linked to the lower horizons of the relict "south-bound" delta at the modern exit of the Semliki River from Lake Rutanzige and to the "lower terrace" with its contained archaeological materials of Ishango type.
26. C. A. Scholz and B. R. Rosendahl, *Science* **240**, 1645 (1988); A. S. Brooks and P. Robertshaw, in *Low Latitudes*, vol. 2 of *The World at 18 000 BP*, O. Soffer and C. Gamble, Eds. (Unwin Hyman, London, 1990), pp. 121–169.
27. Interpreting chronology from weathering and sedimentation in such a complex of carbonate paleosols is fraught with difficulties. Without more comparable exposures, unseen local causes cannot be totally dismissed. Nonetheless, the impression of major, multiple changes in soil and meteorological climate is the simplest interpretation.
28. Because the bulk ash cover is absent at the two Ishango sites, which are located on low benches or terrace remnants about 10 to 12 m above the river, the exact relationship of the Ishango sequence to the Katanda sequence is problematic. The date from the top of the ash at Kabale, located between Ishango and Katanda, suggests that most volcanic activity predated ~7000 years B.P. Bulk ash deposition may also correlate with the large-scale extinction of Nilotic fauna in the lake, which is posterior to the main Ishango horizons. That these Ishangian horizons are younger than the ASB paleosol and lower Katanda beds is further demonstrated by a section at Kabale 7, in which the ASB paleosol is overlain by well-sorted yellow sands typical of the lower Katanda beds, yielding a single quartz artifact. These sands were overlain in turn by successive horizons of poorly sorted sands and gravels containing numerous mollusk shells of the same age as those at the Ishango site (Is11), as determined by AAR. The upper layers were ashy and cemented, comparable to the upper "tufacés" level at Ishango. This demonstrates that the lower Katanda beds and ASB paleosol clearly predate the Ishangian (~20 to 25 ka), although contemporaneity of the upper Katanda beds with all or part of the Ishangian horizons is a possibility.
29. Kanimba Misago, in (*8*), pp. 301–316.
30. This locality is described in detail in (*17*). It was discovered in 1988 by J.V.
31. Dates associated with MSA Kalinian (Lupemban) material from the Gombe site near Kinshasa may be older than 43.8 ka [D. Cahen, *L'Anthropologie* **80**, 573 (1986)].
32. J. E. Kokis, thesis, George Washington University, Washington, DC (1988).
33. The Mumba MSA industries, however, contain a larger proportion of formal stone artifacts, especially small well-made points, which are largely absent at the Katanda sites.
34. F. van Noten, *Antiquity* **51**, 35 (1977).
35. Some of these, such as the topi, may have been present in the area as recently as 130 years ago; their recent disappearance may be due to a combination of human hunting pressure, interspecies competition, and encroachment of woodland habitats after the decimation of the region's elephants [T. E. Mugangu, *Mammalia* **53** (no. 4), 511 (1989); personal communication].
36. R. Kaylor *et al.*, *Anc. T L* **11**, 40 (1993).
37. H. Schwarcz and R. Grun, *Proc. R. Soc. London Ser. B* **337**, 145 (1992).
38. H. Schwarcz and J. Rink, in preparation.
39. R. Grun, H. P. Schwarcz, S. Zymela, *Can. J. Earth Sci.* **24**, 1022 (1987). Enamel was cleaned of attached dentine, crushed, and sieved. Aliquots were irradiated with ^{60}Co-rays; the intensity of the g = 2.0018 ESR signal was used to construct an additive dose-response curve, from which an equivalent dose was obtained by extrapolation. Attached sediment was used to calculate external beta dose. U, Th, and

K were determined in enamel and sediment by instrumental neutron activation analysis. We assumed a water content of 10 ± 10% and no radon loss.
40. The estimated error is simply the 1σ standard deviation of the six ages.
41. F. McDermott, R. Grun, C. B. Stringer, C. J. Hawkesworth, *Nature* **363**, 252 (1993).
42. Each quoted error is the 1σ analytical precision on one sample.
43. R. Grun, H. P. Schwarcz, J. Chadam, *Nucl. Tracks Radiat. Meas.* **14**, 237 (1988).
44. In this estimate of error, we have reduced the analytical uncertainty of the average ESR age to reflect the difference of 7 ka between the minimum EU age of 67 ka and the minimum TL age of 74 ka for the overlying stratigraphic unit.
45. G. H. Miller, P. B. Beaumont, A. T. Jull, B. Johnson, *Proc. R. Soc. London Ser. B* **337**, 149 (1992); A. S. Brooks, P. E. Hare, J. E. Kokis, *Carnegie Inst. Washington Yearb.* **92**, 95 (1993); P. E. Hare, G. A. Goodfriend, A. S. Brooks, J. E. Kokis, D. W. Von Endt, *ibid.*, pp. 80–85.
46. We thank the people and the government of the Republic of Zaire, especially the Président Délégué Général (PDG) for the Institut Zairois pour la Conservation de la Nature, Mankoto wa Mbalele, and the PDG of the Institut des Musees Nationaux, Lema Gwete, for facilitating this research. We also acknowledge the support and contributions in the field of the project co-principal investigators N. T. Boaz and J. W. K. Harris and of Kanimba Misago (archaeologist, Musees Nationaux), Mugangu Trinto Enama (Director of Graduate Studies, University of Kinshasa), and Muya wa Bitanko Kamuanga (Director, Museum de Lubumbashi). The research was supported by the National Science Foundation under grants to N. T. Boaz, J. W. K. Harris, and A.S.B. (BNS85-07891, BNS86-08269, and BNS90-14092), to W.H. and A.F. (86-02272, 89-11758, 90-47367, 91-07652, and 92-40147), and to H.S. (DBS92-10469), as well as by grants from the L. S. B. Leakey Foundation, the National Geographic Society, the George Washington University Committee on Research, Sigma Xi, Earthwatch, the Holt Family Foundation, and the Social Sciences and Humanities Council of Canada (K.S.). We are indebted to J. de Heinzelin for his work on the sections of Kt2 and Kt9 and for helpful comments on earlier drafts. The drawings were prepared by D.M.H.

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A Middle Stone Age Worked Bone Industry from Katanda, Upper Semliki Valley, Zaire

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Three archaeological sites at Katanda on the Upper Semliki River in the Western Rift Valley of Zaire have provided evidence for a well-developed bone industry in a Middle Stone Age context. Artifacts include both barbed and unbarbed points as well as a daggerlike object. Dating by both direct and indirect means indicate an age of ~90,000 years or older. Together with abundant fish (primarily catfish) remains, the bone technology indicates that a complex subsistence specialization had developed in Africa by this time. The level of behavioral competence required is consistent with that of upper Paleolithic *Homo sapiens sapiens*. These data support an African origin of behaviorally as well as biologically modern humans.

Anatomically modern humans (*Homo sapiens sapiens*) appeared in Africa and the Levant before 90,000 years ago (ka) (*1*). By 50 ka, they had colonized Australia (*2*) and possibly east Asia (*3*). In the colder climates of Europe, central Asia, and Siberia, however, Neandertals (*Homo sapiens neandertalensis*) continued to predominate until as late as 35 ka. The middle to upper Paleolithic behavioral transition in Europe, central Asia, Siberia, and the Near East also occurred between 40 and 30 ka and is marked by the appearance of (i) new technologies, such as prismatic blade cores, specialized bone and antler tools, burins, and sophisticated hearths, (ii) more complex economic strategies, involving seasonally specific activities, storage, and long-distance procurement, (iii) larger scale social networks, reflected not only in the long-distance trade in raw materials but also in the use of personal ornaments, and (iv) an expanded use of symbols in art and daily life. Regionally specific styles of artifact manufacture in the early upper Paleolithic reflect this greater social complexity. In Europe, with a few exceptions from the transitional period (*4*), the evolutionary shifts in human morphology and behavior coincide; anatomically modern humans are associated with upper Paleolithic industries, whereas Neandertals are associated with middle Paleolithic or Mousterian industries.

In Africa, however, fossils of anatomically modern humans from between 130 and ~60 ka are associated with industries grouped as Middle Stone Age (MSA), which share broad technological parallels with the Mousterian–middle Paleolithic of western Eurasia (*5*). By ~40 ka, these flake and prepared-core industries begin to be replaced, at least in some areas, by Later Stone Age (LSA) industries based primarily on microlithic technology rather than on blades (*6*). This new technology is associated with other indicators of greater behavioral complexity such as bone tools, ostrich eggshell beads, and transport of raw materials over long distances. The extent to which the MSA differs from the Mousterian in foreshadowing this complexity is uncertain (*7*).

We have recently recovered evidence for early complex behavior in the MSA from three sites at Katanda (Kt2, Kt9, and Kt16), a multisite locality in the Upper Semliki Valley of eastern Zaire, ~6 km north of Ishango, where the Semliki River exits from Lake Rutanzige (formerly Lake Edward) (*8*). The Katanda materials include a formal (*9*) bone industry, consisting of barbed bone points, unbarbed points, and a flat dagger. Bone industries from other African sites are considerably younger. Upstream at Ishango, uniserial and biserial barbed points have been dated to ~25 ka (*10*, *11*). Outside Africa, formal bone points with finished bases suggestive of hafting first appear in the European Aurignacian as early as 38 to 40 ka (*12*); barbed points, however, do not occur before ~14 to 12 ka (*13*) at sites throughout Eurasia. Here we describe the artifact horizon at Kt9 with occasional reference to materials from Kt2 and Kt16. Paleoenvironmental data (*8*) suggest that all three Katanda sites were located along the valley of a southward-flowing proto-Semliki River, fringed with relatively dense gallery forest in proximity to open savannas. Sediment analyses indicate that Kt9 was the closest of the three to the proto-Semliki channel (*14*).

Excavation at Kt2 began in 1986 and continued through 1990, exposing 21 m^2 in the MSA levels. Three horizons of MSA were distinguished. The lowest, resting on the ASB paleosol, is the most comparable stratigraphically to the MSA horizons at Kt9 and Kt16. Over 2700 lithics in quartz, quartzite, and chert and 1100 faunal remains of fish and mammals were recovered from this lower horizon. The upper two MSA horizons yielded a total of 3700 lithics, predominantly in quartz, and some 75 poorly preserved faunal remains of which only 10 fragments were identifiable. Discoidal cores were the most distinctive aspect of the lithic material; formal tools were rare. In 1990, a single large fusiform bone point was recovered from the lowest MSA horizon in contact with the paleosol.

At Kt9, the MSA horizon crops out on a steep cliff face below ~8 m of horizontally

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