LETTER

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Ancient herders enriched and restructured African grasslands

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Grasslands are one of the world's most extensive terrestrial biomes and are central to the survival of herders, their livestock and diverse communities of large wild mammals[1–3]. In Africa, tropical soils are predominantly nutrient-limited[4–6] but productive grassy patches in wooded grassland savannah ecosystems[2,4] grow on fertile soils created by geologic and edaphic factors, megafauna, fire and termites[4–6]. Mobile pastoralists also create soil-fertility hotspots by penning their herds at night, which concentrates excrement—and thus nutrients—from grazing of the surrounding savannahs[7–11]. Historical anthropogenic hotspots produce high-quality forage, attract wildlife and increase spatial heterogeneity in African savannahs[4,12–15]. Archaeological research suggests this effect extends back at least 1,000 years[16–19] but little is known about nutrient persistence at millennial scales. Here we use chemical, isotopic and sedimentary analyses to show high nutrient and ^{15}N enrichment in on-site degraded dung deposits relative to off-site soils at five Pastoral Neolithic[20] sites (radiocarbon dated to between 3,700 and 1,550 calibrated years before present (cal. BP)). This study demonstrates the longevity of nutrient hotspots and the long-term legacy of ancient herders, whose settlements enriched and diversified African savannah landscapes over three millennia.

Grassy glades—anthropogenic soil nutrient hotspots—on recent herder settlements increase biodiversity at a landscape scale and influence savannah ecosystem structure and function[4,12–15]. Although the processes creating these glades are well-understood[7–9,12–15], the full time-depth of their creation and effects on African savannahs are as yet unexplored. To investigate the longevity of anthropogenic soil nutrient hotspots, we excavated three Pastoral Neolithic sites located west of the Rift Valley in Ntuka, Narok County, Kenya: Indapi Dapo (site code GvJh121), Oloika 1 (GvJh85), Oloika 2 (GvJh86) and sampled two (GvJm44 and GvJm48) at Lukenya Hill, located to the east of the Rift Valley (Fig. 1, Extended Data Fig. 1, Extended Data Table 1).The sites are located in the Loita–Mara–Serengeti ecosystem and Athi-Kapiti plains. Accelerated mass spectrometry radiocarbon dates for the Ntuka sites range from 2,450 to 2,000 cal. BP and the radiocarbon dates from the Lukenya sites range from 3,700 to 1,550 cal. BP, spanning the earliest to the latest phases of the Pastoral Neolithic[20] (Extended Data Table 2). Lithic and ceramic technologies[20] indicate that the Oloika sites are members of the Elmenteitan tradition of the Pastoral Neolithic; Indapi Dapo and Lukenya sites belong to the Savannah Pastoral Neolithic tradition (Supplementary Information). The archaeological sites are 60–140 m in diameter (Fig. 1f, g, Extended Data Table 1). All of the sites in the Ntuka study area are located in structurally open grassy patches within wooded savannah grassland. Glades, Pastoral Neolithic sites and abandoned modern settlements are visible as well-defined hectare-scale treeless grassy features on the ground and in satellite imagery (Fig. 1e–g, Extended Data Fig. 2).

A visually distinct grey fine-grained sediment layer, 15–30-cm thick (Fig. 1b–d, Extended Data Fig. 1), occurs in four sites (Oloika 1 and 2, Indapi Dapo and GvJm48) and is discontinuous at the oldest site (GvJm44) (Supplementary Note). Micromorphology shows this grey sediment originates from degraded dung (Extended Data Fig. 2). Colour, texture and structure differ between on-site and off-site sediments (Fig. 1b–d). Phytoliths and dung spherulites[9] are present in Ntuka on-site sediments and absent in off-site sediments (Extended Data Fig. 3).

Particle size analysis demonstrates that on-site sediments are dominated by silt, relative to coarser sandy off-site samples, and that organic matter and carbonate percentages are higher on-site (Extended Data Fig. 4, Extended Data Table 1). Fourier transform infrared spectroscopy shows that opal and calcite are present in on-site samples at Ntuka sites. Opal originates from silt-sized grass phytoliths. Calcite appears in thin sections as dung spherulites or as microspar (Extended Data Fig. 3). Lukenya Hill sediments do not show substantial mineralogical differences from off-site samples. However, inductively coupled plasma mass spectrometry analyses demonstrate that phosphorous, nitrogen, magnesium and calcium are enriched by an order of magnitude in on- versus off-site samples (Fig. 2, Supplementary Table 1). In some cases, calcium concentrations were elevated by 200–1,000% in on-site sediments. These findings are consistent with the enrichment observed in contemporary pastoral settlements (Supplementary Table 2). Nitrogen and carbon isotope ratios are consistently higher in degraded dung deposits than in natural off-site soils, except at Lukenya site GvJm 48 (Fig. 3, Supplementary Table 1). Supplementary Table 2 summarizes metadata from Africa regarding nutrient elevation, and the distinctive vegetation and ecology of historical and Iron Age herder corrals.

Our analyses of micromorphology, mineralogy, and chemical and isotopic composition reveal that elevated levels of nutrients persist for 3,000 years in decomposed dung at Neolithic herder sites in the grasslands of southern Kenya. Our interpretations of the archaeological data are based on ethno-archaeological and ecological studies of contemporary pastoral settlements that show enrichment in weight percentage (wt%) N and ^{15}N of soil organic matter, grass phytoliths, dung spherulites and mineral nutrients (especially phosphorous and calcium), relative to off-site samples[8,18,21,22]. Nitrogen in cattle and sheep and goat dung is enriched in ^{15}N because dung is composed of a mixture of both excreted undigested plant material and ^{15}N-enriched proteinaceous material from the animals themselves[18,22]. Volatilization of ^{15}N-depleted ammonia from dung and urine decomposition in semi-arid environments also increases soil $\delta^{15}N$[21,23]. Soil organic $\delta^{13}C$ values on archaeological sites are significantly higher than off-site values, and the highest $\delta^{13}C$ values are associated with the highest $\delta^{15}N$ values. This pattern is consistent with soil organic carbon and nitrogen being derived from dung and urine excreted by herbivores that graze on C_4 plants. Phosphorous originates from the organic component of dung[24,25]. Calcium carbonate is concentrated in decomposed dung in the form of dung spherulites, which elevate calcium levels. Bones are additional sources of phosphate, magnesium and calcium. The presence

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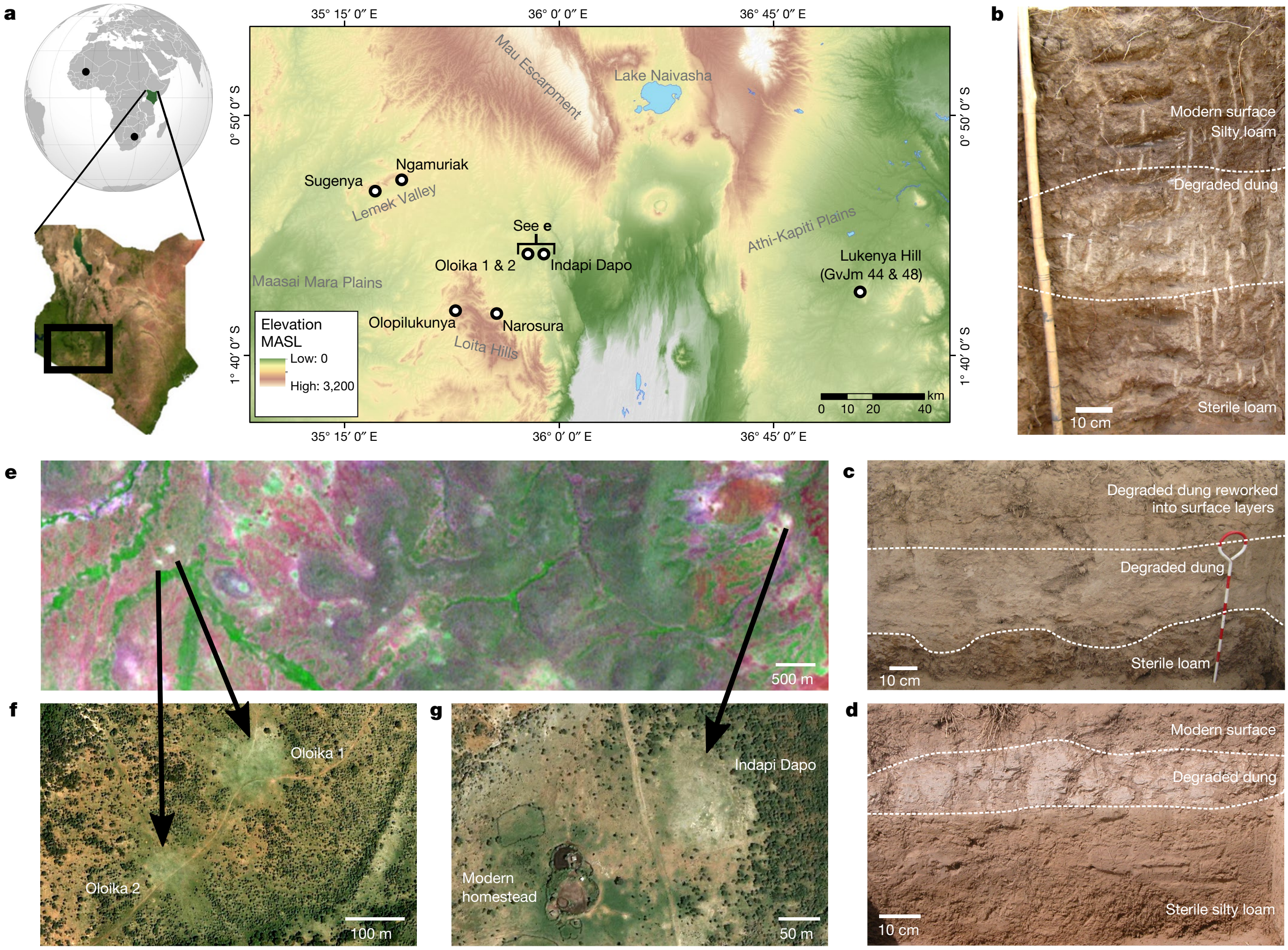

Fig. 1 | Study areas and sampled sites. **a**, Distribution of Pastoral Neolithic sites in southwestern Kenya. MASL, metres above sealevel. Digital elevation data from NASA SRTM. **b–d**, Dung deposits visible in profiles at 1,500–3,000-year-old herder settlements at Lukenya Hill (GvJm48, **b**), Oloika 2 (**c**) and Indapi Dapo (**d**). **e**, False-colour LANDSAT-7 image of Narok county Ntuka study area on 3 February 2003, Oloika 1, Oloika 2 and Indapi Dapo site glades are visible as white patches, and modern Maasai settlements as dark red patches. **f**, **g**, High nutrient legacies encourage open grassy plant succession relative to bushy off-site vegetation at Oloika 1 and Oloika 2 (**f**), and Indapi Dapo (**g**). Globe in **a**, CC BY 2.0 licence. **b–d**, Photographs by F.M. **f**, **g**, Imagery from Google Earth Pro, Digital Globe.

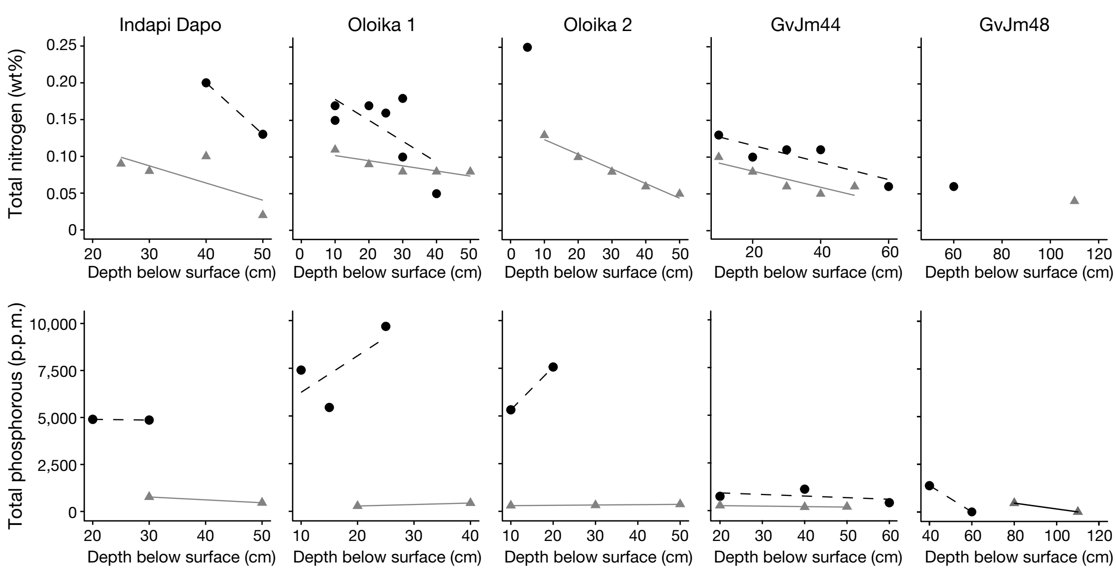

Fig. 2 | Elemental nitrogen and phosphorous concentrations in sediment from on- and off-site stratigraphic sections. Elemental nitrogen (top) and phosphorous (bottom) concentrations in sediments from on-site (black circles, $n = 16$ for N and $n = 12$ for P) and off-site (grey triangles, $n = 20$ for N and $n = 12$ for P) stratigraphic sections at the sampled archaeological sites. All samples are independent. Least-squares regressions plotted as dashed lines for on-site samples and solid lines for off-site samples.

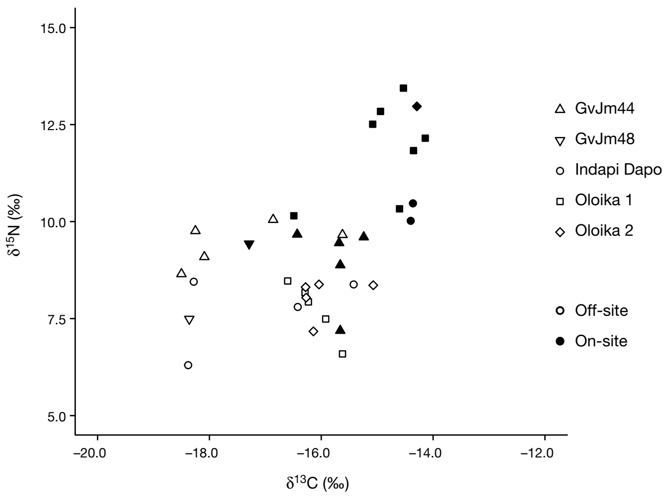

Fig. 3 | $\delta^{13}C$ and $\delta^{15}N$ values measured in on-site and off-site sediment samples from five archaeological sites in East Africa. On-site samples, closed symbols ($n=16$); off-site samples, open symbols ($n=20$). All samples are independent.

of microspar suggests that dung spherulites dissolved and calcite re-precipitated as microspar. This is supported by the presence of manganese-oxide florets in thin sections, suggesting occasional hydromorphic conditions at some sites. The precipitation of microbially mediated carbonates[22] and translocation of carbonate-rich solutions down profiles[9] resulted in the formation of basal calcitic crusts.

A previous study of a 40-year time series of abandoned Maasai pastoral settlements in Kenya demonstrated that organic matter content declines substantially after about 20–30 years[9]. Mineralogical cascades triggered by the products of organic matter (for example, formation of phosphate minerals) stabilize at this point in diagenesis, sites become more deeply buried and minerals and elements may persist for millennia[9,25]. Continued enrichment of pastoral corral sediments by wild ungulates and domestic herds attracted to palatable forage, and soil–plant–herbivore feedbacks may contribute to persistence of anthropogenic hotspots[7,11,15]. Our results, as well as geochemical analyses of the Pastoral Neolithic site of Sugenya[18], reveal the persistence of nutrient-enriched dung-derived deposits over three millennia.

These findings reinforce the environmental importance of the fertile grassy patches created by the earliest southern Kenyan pastoralists. Widespread settlements generated nutrient-enriched, hectare-scale microhabitats. Neolithic, Iron Age and recent herder sites are visible in satellite images of the Ntuka area as glades (4,400–15,000 m^2 in size) (Fig. 1e–g, Extended Data Fig. 2d). Research on the Laikipia Plateau of Central Kenya complements Pastoral Neolithic findings, extending our understanding of nutrient stabilization and glade landscapes into the Pastoral Iron Age. The seventeenth–eighteenth-century-AD settlement of Maili Sita preserves phytoliths, spherulites and elevated nutrients in dung deposits that support characteristic grass species[19]. The fifteenth-century-AD Maasai Plains and unexcavated sites on the Laikipia Plateau reveal a broad distribution of 15–45-ha pastoral glades[26]. Pastoral Neolithic and Iron Age sites in diverse Kenyan savannahs demonstrate the spatial influences of niche construction by pastoralists on soil nutrients and savannah heterogeneity, on timescales that range from five centuries to three millennia.

Influences of the settlements of ancient and recent mobile herders in eastern Africa create landscape palimpsests. Recent herders make similar choices about where to locate their settlements to ancient ones with regard to slope and distance from water[27,28]. As a result, contemporary Maasai herders settle on or near Pastoral Neolithic settlements in the Lemek Valley[29] and Ntuka areas of southwest Kenya (Fig. 1g, Extended Data Fig. 5). Such settlement clusters are also attractive to modern herders because of the proximity of nutrient-rich grazing that supports growth and lactation (for example, for calves)[3,7]. Studies of Maasai settlements constructed over the last 60–100 years suggest that 1–20% of savannahs, and most land near water, has been settled over the past 100 years[12,27].

East African findings draw attention to the temporal and spatial scale of pastoral legacies. Metadata on modern and ancient African pastoral settlements indicate that influences on nutrient enrichment and ecology are broadly dispersed (Supplementary Table 2). Ecological research on a South African Iron Age site in the Nylsvley, Nature Reserve Limpopo Province (about 700 years old), compares modern glade formation processes in South Africa, the Sahel and eastern Africa (marked on Fig. 1a) and documents increased biodiversity and forage quality on this ancient anthropogenic hotspot[4]. In the Limpopo Valley and eastern Botswana, corrals in Iron Age settlements (about 1,200–500 years old) (Supplementary Table 2) are characterized by grassy vegetation and eutrophic dung-derived soils[16,17]. Landscape-scale on- and off-site studies have the potential to resolve ancient patterns at finer scales. However, biogeochemical data on Neolithic and other East African sites, and ecological and nutrient data from widespread Iron Age and historic sites, indicate that herders have had a role in structuring and diversifying African savannah ecosystems for up to three millennia.

Outside Africa, reinforced nutrient enrichment related to Iron Age pastoral activity in arid environments has also been documented in the southern Levant[30]. Exploration of nutrient enrichment by ancient pastoral settlements in temperate and high-altitude grasslands in Central Asia[31] and South America[32] will yield insights into local and regional variability and the global importance of prehistoric herder influences on nutrient flows and grassland ecology.

Online content

Any methods, additional references, Nature Research reporting summaries, source data, statements of data availability and associated accession codes are available at https://doi.org/10.1038/s41586-018-0456-9.

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Competing interests The authors declare no competing interests.

Additional information
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METHODS

No statistical methods were used to predetermine sample sizes.

Soil profiles and samples from excavations. Sites were identified in the Ntuka region during site surveys by S.H.A. before 2011. Surface exposures and animal burrows in Pastoral Neolithic sites were examined in 2011 for potential corral areas. Excavation proceeded by 5-cm spits or natural levels, where detected. All finds were screened through 5-mm mesh. Samples were taken within excavations for micromorphology, flotation and sediment analyses. Off-site samples were taken 30–40 m from the edges of archaeological sites, in bush-dominated microhabitats.

Sediment analyses. Elemental analysis of bulk sediment samples used an Agilent 7750 ICP-MS. Dried samples (∼0.1 g) were digested in concentrated HNO_3 in a Mars-6 microwave digester at 180 °C for one hour. After digestion, the supernatant was diluted to a 10× solution, filtered through a 0.22-μm filter and diluted again to make a final 100× solution. Internal reference standards and HNO_3 blanks were used to calibrate the ICP-MS. Potential memory effects were monitored by running blanks after every 5 samples and drift monitored by running internal standards after every 15 samples. Particle size, loss on ignition, magnetic susceptibility and chemical composition analyses were conducted at the Geoarchaeology and Nano facilities at Washington University in St. Louis. Micromorphology and FTIR analyses were performed at the Laboratory for Sedimentary Archaeology, University of Haifa (see Supplementary Information).

Stable isotopes. Analyses on bulk sediment samples were carried out at Washington University in St Louis, using a Flash 2000 elemental analyser coupled to a Thermo Delta V Plus continuous-flow isotope ratio mass spectrometer. Samples were homogenized in an agate mortar, and pestle-and-sieved to a particle size of <250 μm. We aimed to analyse at least 20 μg of nitrogen, so 15–80 mg of sediment was weighed into 5 × 9-mm tin capsules. Samples for carbon isotope analysis were treated to remove carbonates with 2 M HCl until effervescence ceased (∼24 h), rinsed 5 times with MQ water, dried in a 70 °C oven, and weighed into 5 × 9-mm tin capsules. Our results are expressed as $\delta^{15}N$ and $\delta^{13}C$ as parts per thousand (‰) relative to AIR and Vienna Pee Dee Belemnite standards, respectively. The average analytical precision for both C and N was <0.2 ‰ based on the standard deviation of 24 replicates of an in-house standard (Bob's Red Mill millet flour) and 18 replicates of a second in-house standard (acetanilide). Weight percentage C and N are estimated based on standards of known elemental composition; wt% precision of these known compounds is better than 0.1%. We used the lme4 package in R to perform a linear mixed effects analysis of the relationship between sediment isotope values and the on-site presence of a dung profile (see Supplementary Information).

Radiocarbon dating. Faunal collagen and enamel apatite samples from Indapi Dapo and Oloika 2 (Extended Data Table 2) were prepared for radiocarbon dating at the Environmental Isotope Paleobiogeochemistry Laboratory, Department of Anthropology, University of Illinois, Urbana, and the Radiocarbon Laboratory of the Illinois State Geological Survey at the University of Illinois. To purify collagen, dentine was demineralized using 0.2 M HCl, rinsed 8× with dH_2O, treated with 0.125 M NaOH to removed soil organic contaminants, rinsed 8× with dH_2O and hydrolysed at 70 °C in 10–3 M HCl. Freeze-dried collagen was converted to CO_2 using sealed-tube combustion, and cryogenically distilled for AMS dating at the UC Irvine Accelerator Mass Spectrometry radiocarbon laboratory. Enamel was separated from dentine and cementum and ground in an agate mortar. A ∼400-mg sample was treated with 25 ml 2.63% NaOCl (sodium hypochlorite) to remove organic matter, rinsed 8× with dH_2O, and reacted with 25 ml 0.1 M acetic acid under vacuum to remove adsorbed and diagenetic carbonate, alternating with return to atmospheric pressure with CO_2-free N_2. Cycling between vacuum and N_2 continued at ∼15–30-min intervals until the bubbling reaction ceased (∼3–4 h). Samples were rinsed 5× in distilled water and freeze dried. Purified samples were reacted with 100% H_3PO_4 and CO_2 from structural carbonate was purified by cryogenic distillation for AMS dating.

Reporting summary. Further information on research design is available in the Nature Research Reporting Summary linked to this paper.

Data availability. All data generated or analysed in this study are included in the paper and its Supplementary Information. Site descriptions are in Supplementary Information, radiocarbon dates in Extended Data Table 2 and particle size, ICPMS, FTIR, isotope and micromorphology data in Supplementary Table 1. Remaining soil samples are curated in the Archaeology Division of the National Museums of Kenya, Nairobi.

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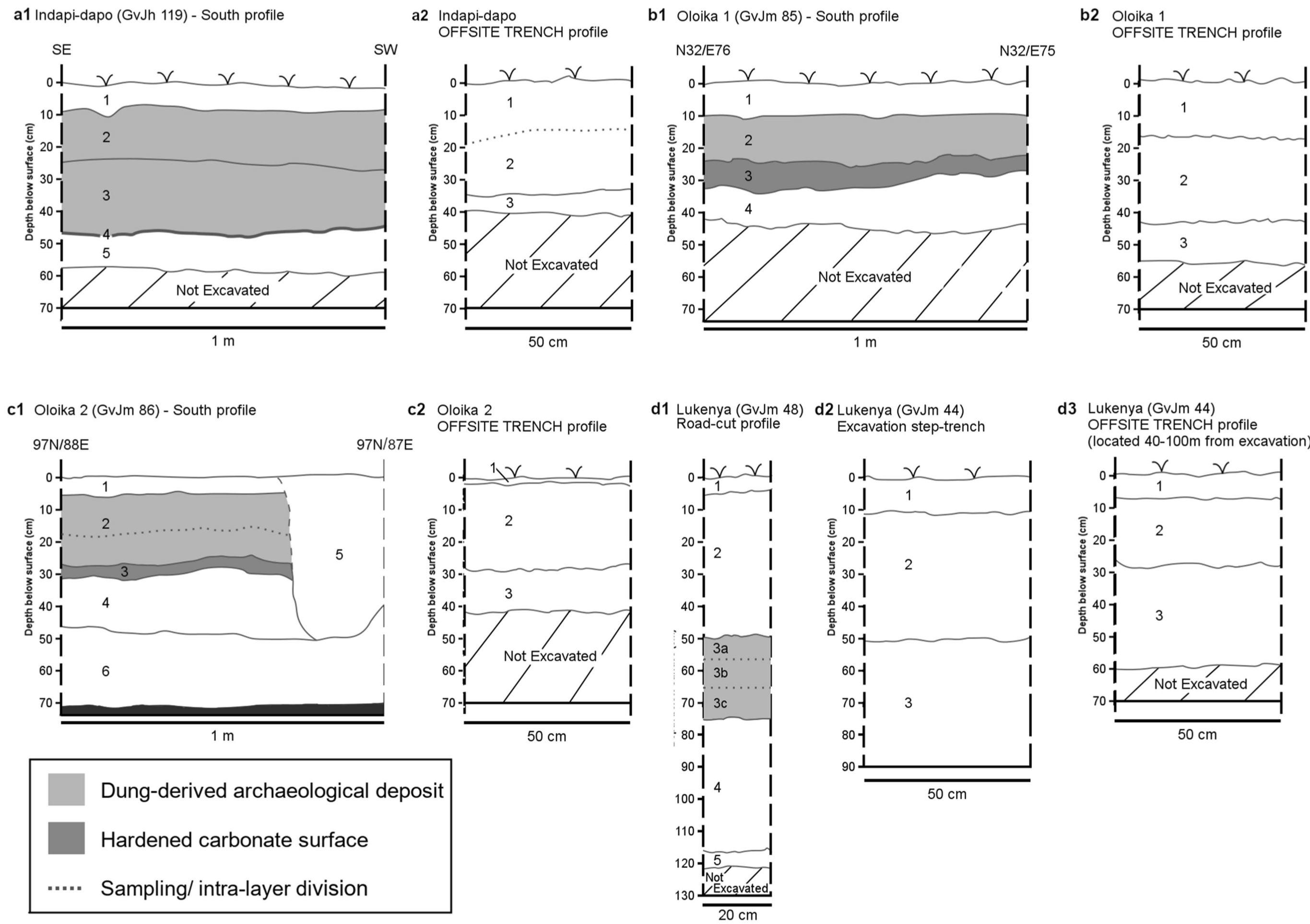
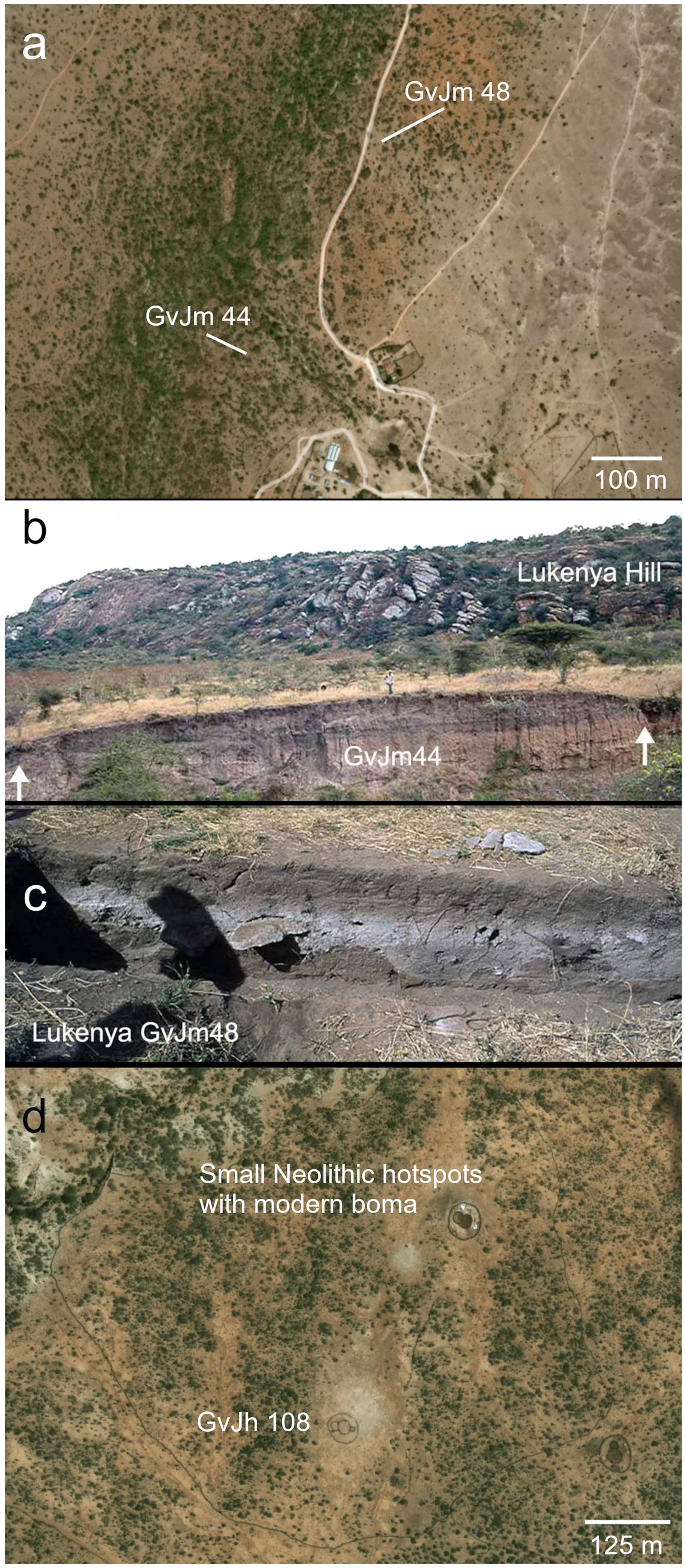
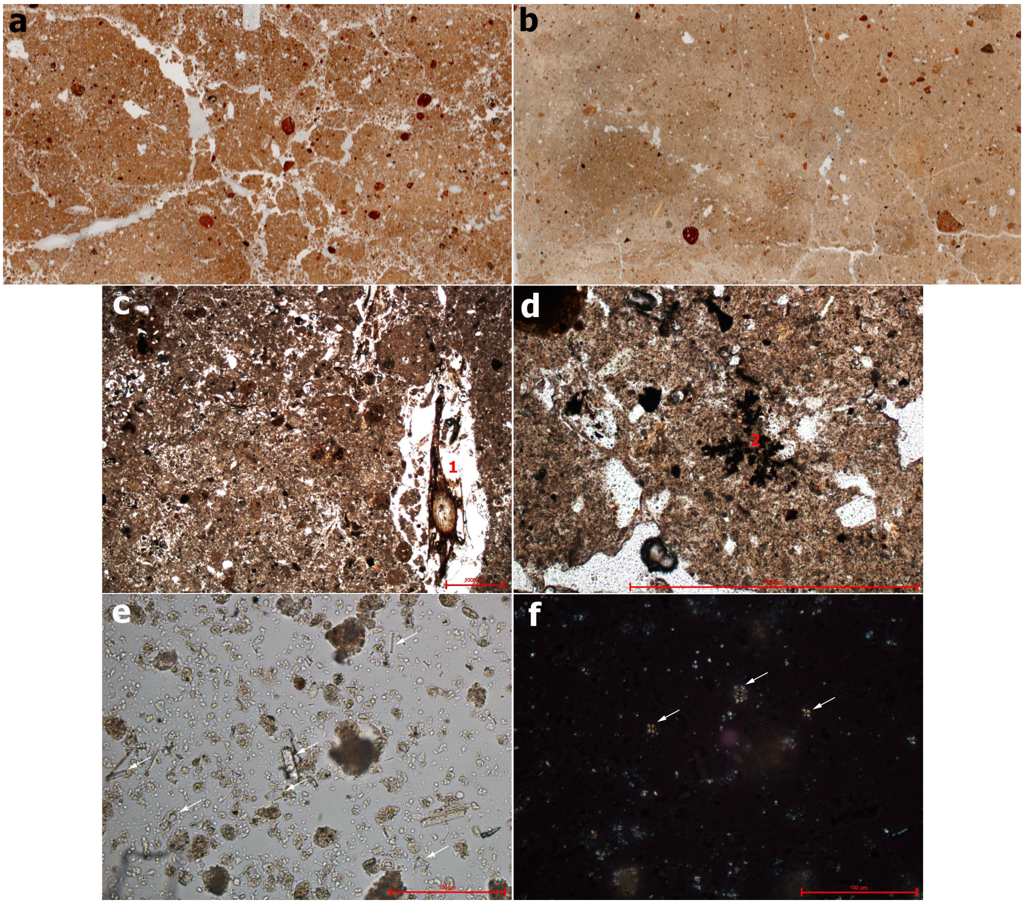


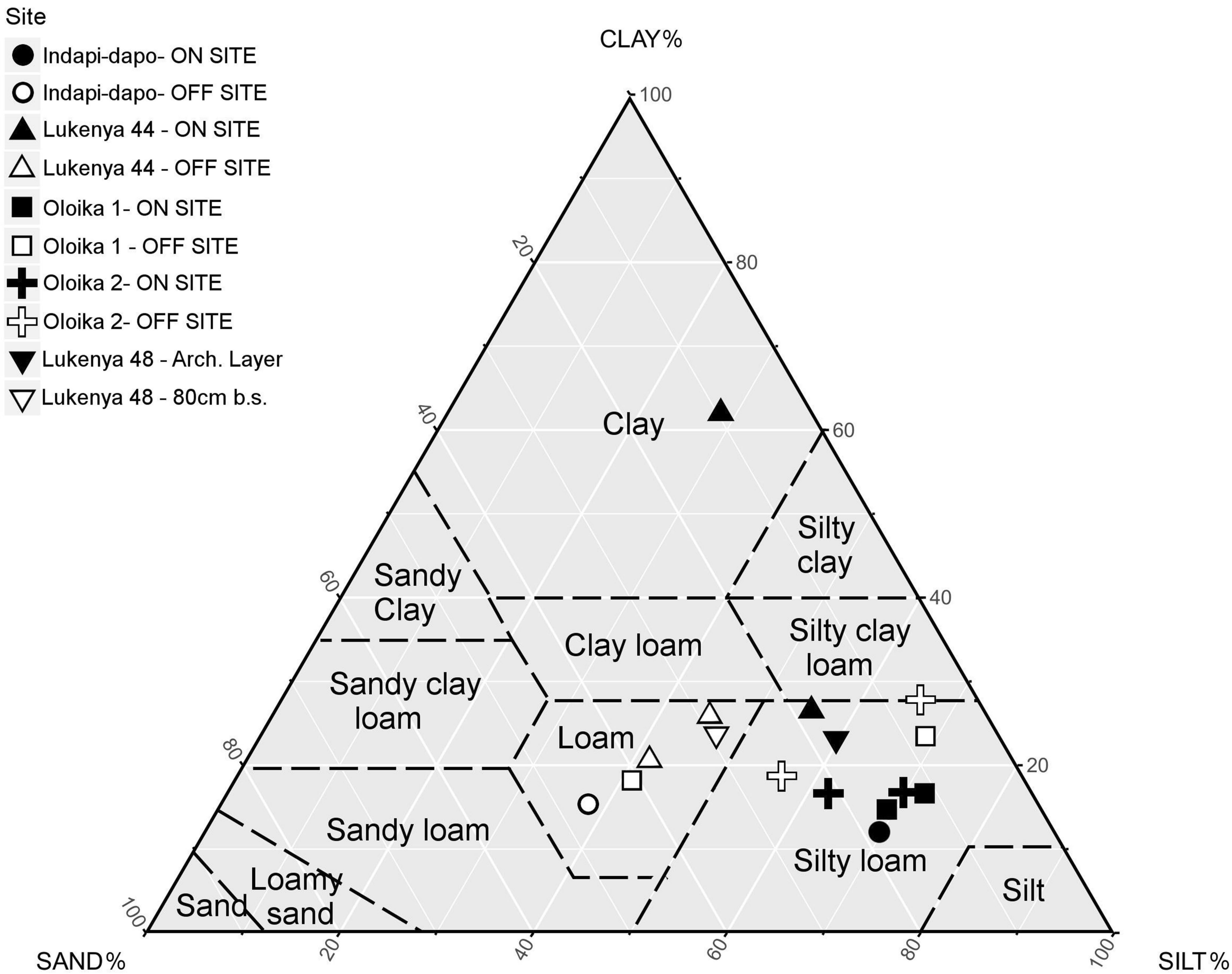
Extended Data Fig. 1 | On-site versus off-site sediment profiles for sampled locales. a, On-site and off-site stratigraphy at Indapi Dapo. a1 depicts on-site stratigraphy: (1) modern topsoil, (2) light grey cultural horizon, (3) light yellow–brown cultural and dung horizon, (4) discontinuous harder trampled surface and (5) dark yellow–brown sterile sediments. a2 depicts off-site stratigraphy: (1) loamy modern topsoil, (2) brown silts with carbonate nodules and (3) rocky bedrock-derived sediment. **b**, On-site and off-site stratigraphy at Oloika 1. b1 depicts on-site stratigraphy: (1) modern topsoil, (2) pale grey cultural and dung horizon, (3) compacted cultural horizon with hard undulating calcium carbonate crust and (4) sterile oxidized palaeosol with manganese nodules. b2 depicts off-site stratigraphy: (1) light brown modern topsoil, (2) grey–brown sediment with carbonate nodules, (3) oxidized subsoil. **c**, On-site and off-site stratigraphy at Oloika 2. c1 depicts on-site stratigraphy: (1) modern topsoil, (2) pale grey cultural and dung horizon, (3) compacted calcium carbonate lens, (4) oxidized subsoil, (5) recent animal burrow and (6) oxidized subsoil pisolithic formation with manganese nodules. c2 depicts off-site stratigraphy: (1) light brown modern topsoil, (2) grey–brown sediment with carbonate nodules and (3) consolidated lighter grey soil with increasing carbonate nodules. **d**, On-site road-cut (GvJm48) and step-trench (GvJm44) stratigraphy, and off-site stratigraphy at GvJm44. d1 depicts the GvJm48 road-cut stratigraphy: (1) modern topsoil, (2) grey–brown silty loam, (3a, 3b, 3c) top, middle and bottom, respectively, of pale grey silty loam cultural and dung horizon, (4) pre-cultural loam palaeosol and (5) bedrock-derived weathered sediments. d2 depicts the GvJm44 step-trench stratigraphy: (1) modern topsoil, (2) dark yellow–brown clay grading to silty loam cultural horizon and (3) lower dark brown silty loam cultural horizon. d3 depicts off-site stratigraphy at GvJm44: (1) modern topsoil, (2) dark brown to red brown sandy loam (3) sandy loam.



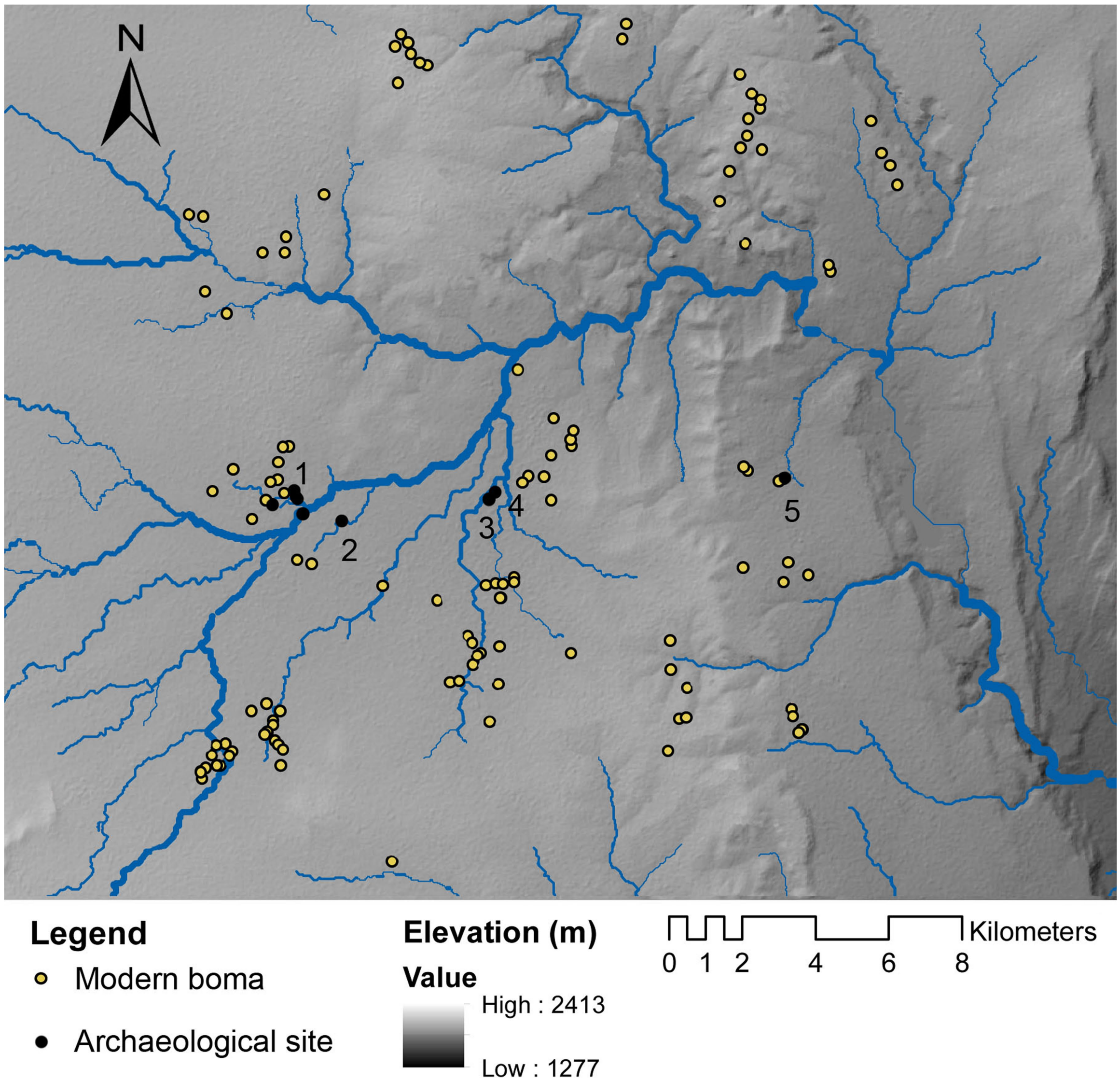
Extended Data Fig. 2 | Archaeological landscapes and stratigraphic sections. a, Satellite image of GvJm44 and GvJm48, Lukenya (dry season). At GvJm48, a track exposes fine-grained grey midden deposits in an open grassy area. Redder sandy clays are exposed north and south of the site. **b**, Landscape and stratigraphic view of GvJm44, showing dark Neolithic midden sediment in cross section. Arrows indicate midden edges. Person standing atop the centre of the midden is about 165-cm tall. **c**, Dung layer at GvJm48. **d**, Open glades visible near the Ntuka River (dry season) at Ol Owarukeri (GvJh108), a large Elmenteitan (Pastoral Neolithic tradition dating to approximately 3,500–1,500 cal. BP) site with modern pastoralist settlement and two smaller Pastoral Neolithic sites, one with modern settlement. **a**, **d**, Imagery from Google Earth Pro, Digital Globe. **b**, **c**, Photographs by S.H.A., 1977–1978.



Extended Data Fig. 3 | Sediment sample micromorphology. **a**, Flatbed scan of a thin section representing off-site sediments (Oloika 1). **b**, Flatbed scan of a thin section representing on-site sediments (Oloika 1). Both scans are 6.2-cm wide. Note the colour and structure differences between on-site and off-site sediments. The reddish rounded particles are weathered local magmatic rock. **c**, Microphotograph of on-site sediments (Indapi Dapo) showing granular microstructure associated with large voids, which indicates severe bioturbation. Note the modern plant root (1) within the large void on the right. Scale bar, 1 mm; plane-polarized light. **d**, Microphotograph of on-site sediments (Indapi Dapo) showing black manganese-oxide florets (2), which indicate periods of water saturation. Scale bar, 1 mm; plane-polarized light. **e**, Microphotograph of on-site sediments (Oloika 2) that have been disaggregated ('grain mount') to enable clear observation of phytoliths and dung spherulites. Arrows point to several phytoliths of various types. Scale bar, 0.1 mm; plane-polarized light. **f**, Same view as in **e**, but in crossed-polarized light. Arrows point to a few dung spherulites.



Extended Data Fig. 4 | Ternary plot of particle size distributions for sampled archaeological and off-site contexts. *n* = 8 archaeological contexts; *n* = 8 off-site contexts. See Supplementary Table 1 for values. Plot generated using the ggtern extension for ggplot2[33].



Extended Data Fig. 5 | Landscape of Nkuta showing 116 modern and 5 ancient pastoral settlements (bomas) visible in the study area. Ole Pariata (1), Ol Owarukeri (GvJh108) (2), Oloika 1 (3), Oloika 2 (4) and Indapi Dapo (5). ArcGIS model with a base 30-m-resolution digital elevation derived from the Shuttle Radar Topography Mission.

Extended Data Table 1 | Archaeology

Site	Lat°/ Long°	Elevation (m)	Tradition	Glade area (m^2)	On-site PSA	Off-site PSA	On-site enriched	Off-site enriched	Carbonate layer
Oloika 1 (GvJh86)	S 1.36705 E 35.9709	1745	Elmenteitan	2320	Silty loam	More sand and clay	P, Mg, K†	Al	thick
Oloika 2 (GvJh85)	S 1.36545 E 35.9001	1745	Elmenteitan	4750	Silty loam	More clay	P, Mg†	Zr, Pb (Al)	thick
Indapi Dapo (GvJh121)	S 1.36176 E 35.9713	1650	Savannah Pastoral Neolithic	8360	Silty loam	More sand	P, Mg, Ca, Sr Na†, K†	Co, V, Ni, Zr, Pb	thin
Vaave Makongo (GvJm44)	S 1.4761 E 37.074	1686	Savannah Pastoral Neolithic	n.d.	Silty loam	More sand	P	n.d.	n.d.
Lukenya (GvJm48)	S 1.47266 E 37.0762	1683	Savannah Pastoral Neolithic	n.d.	Silty loam	More sand	Ca, P†, Mg†, Na†	n.d.	n.d.

n.d., no data. PSA, particle size analysis.
†Questionable or moderate enrichment.

Extended Data Table 2 | Radiocarbon dates

Site & material culture	Material	Lab #	C14 years	Calibrated years BP*	Reference
Indapi dapo (SPN, Narosura)	tooth dentine collagen	ISGS A3371	2420 ± 20	2461-2364	Reported here
Indapi dapo (SPN, Narosura)	tooth enamel apatite	ISGS A3372	2330 ± 15	2352-2342	Reported here
Oloika 1 GvJh85 (Elmenteitan)	charcoal	ISGS A2076	2420 ± 20	2461-2364	Reported here
Oloika 2 GvJh86 (Elmenteitan)	tooth enamel apatite	ISGS A2125	2095 ± 15	2113-2011	Reported here
Sugenya, (upper dung)	charcoal	Pta-9058	2230 ± 60	2312-2167	36
Sugenya, (lower dung)	charcoal	Pta-9063	2680 ± 60	2853-2764	36
GvJm44 Lukenya (SPN, Nderit)	charcoal	GX5348	3290 ± 145	3703-3361	37
GvJm44 Lukenya, (SPN, Narosura)	charcoal	GX5138	2415 ± 155	2714-2345	37
GvJm44 Lukenya, (SPN, Narosura)	bone apatite	GX4160-A	2085 ± 135	2301-1899	38
GvJm44 Lukenya, (SPN, Narosura)	bone collagen	GX4161-C	1710 ± 135	1813-1422	38
GvJm44 Lukenya, (SPN, Akira)	bone gelatin	GX5638-G	2070 +155	2305-1875	38
GvJm44 Lukenya, (SPN, Akira)	bone apatite	GX4507-A	2030 ± 125	2150-1830	38
GvJm44 Lukenya, (SPN, Akira)	bone apatite	GX5638-A	1820 ± 200	1990-1531	37
GvJm48 Lukenya (SPN, Narosura)	bone gelatin	GX5347-G	1810 ± 135	1879-1569	37
GvJm48 Lukenya, (SPN, Narosura)	bone apatite	GX5347-A	1600 ± 130	1685-1354	37

SPN, Savannah Pastoral Neolithic.
*68.2% confidence interval. Calibrated using SHCAL13 in OxCal 4.2[34–38].

nature research

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☐ Initial submission ☐ Revised version ☒ Final submission

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Experimental design

1. Sample size

Describe how sample size was determined.

This study was not experimental. We discovered new Pastoral Neolithic sites and collected on and off site samples from all but one known PN site with excellent preservation of animal dung. All samples collected in the field were analyzed.

2. Data exclusions

Describe any data exclusions.

No data were excluded.

3. Replication

Describe whether the experimental findings were reliably reproduced.

No experiments were conducted

4. Randomization

Describe how samples/organisms/participants were allocated into experimental groups.

N/A Experiments were not allocated into groups

5. Blinding

Describe whether the investigators were blinded to group allocation during data collection and/or analysis.

N/A Experiments were not conducted. Samples codes did not immediately indicate whether samples were on or off site.

Note: all studies involving animals and/or human research participants must disclose whether blinding and randomization were used.

6. Statistical parameters

For all figures and tables that use statistical methods, confirm that the following items are present in relevant figure legends (or in the Methods section if additional space is needed).

n/a	Confirmed	
☐	☒	The exact sample size (*n*) for each experimental group/condition, given as a discrete number and unit of measurement (animals, litters, cultures, etc.)
☐	☒	A description of how samples were collected, noting whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☒	☐	A statement indicating how many times each experiment was replicated
☐	☒	The statistical test(s) used and whether they are one- or two-sided (note: only common tests should be described solely by name; more complex techniques should be described in the Methods section)
☐	☒	A description of any assumptions or corrections, such as an adjustment for multiple comparisons
☐	☒	The test results (e.g. *P* values) given as exact values whenever possible and with confidence intervals noted
☐	☒	A clear description of statistics including central tendency (e.g. median, mean) and variation (e.g. standard deviation, interquartile range)
☐	☒	Clearly defined error bars

See the web collection on statistics for biologists for further resources and guidance.

Software

Policy information about availability of computer code

7. Software

Describe the software used to analyze the data in this study.	*R described in methods*

For manuscripts utilizing custom algorithms or software that are central to the paper but not yet described in the published literature, software must be made available to editors and reviewers upon request. We strongly encourage code deposition in a community repository (e.g. GitHub). *Nature Methods* guidance for providing algorithms and software for publication provides further information on this topic.

Materials and reagents

Policy information about availability of materials

8. Materials availability

Indicate whether there are restrictions on availability of unique materials or if these materials are only available for distribution by a for-profit company.	*Soil samples remaining are curated in the Archaeology Division of the National Museums of Kenya*

9. Antibodies

Describe the antibodies used and how they were validated for use in the system under study (i.e. assay and species).	*N/A*

10. Eukaryotic cell lines

a. State the source of each eukaryotic cell line used.	*N/A*
b. Describe the method of cell line authentication used.	N/A
c. Report whether the cell lines were tested for mycoplasma contamination.	N/A
d. If any of the cell lines used are listed in the database of commonly misidentified cell lines maintained by ICLAC, provide a scientific rationale for their use.	N/A

Animals and human research participants

Policy information about studies involving animals; when reporting animal research, follow the ARRIVE guidelines

11. Description of research animals

Provide details on animals and/or animal-derived materials used in the study.	*N/A.*

Policy information about studies involving human research participants

12. Description of human research participants

Describe the covariate-relevant population characteristics of the human research participants.	*N/A*