



Geo-Ethnoarchaeology of Pastoral Sites: The Identification of Livestock Enclosures in Abandoned Maasai Settlements

Ruth Shahack-Gross

*Anthropology Dept., Washington University, One Brookings Drive, St Louis, MO 63130, U.S.A. and
Dept. of Structural Biology, Weizmann Institute of Science, Rehovot 76100, Israel*

Fiona Marshall

Anthropology Dept., Washington University, One Brookings Drive, St Louis, MO 63130, U.S.A.

Steve Weiner*

Dept. of Structural Biology, Weizmann Institute of Science, Rehovot 76100, Israel

(Received 21 December 2001, revised manuscript accepted 14 May 2002)

The earliest food producers in Africa were mobile pastoralists who left limited archaeological traces. As a result archaeologists studying the spread of food production in the region have difficulty distinguishing early pastoralists from hunter-gatherers with whom they interacted. This geo-ethnoarchaeological study contributes to the resolution of the problem through identification of sediments distinctive of livestock enclosures, and thus of pastoral settlements. Sediments were sampled in and around currently occupied and recently abandoned Maasai livestock enclosures ranging in age between one and 40 years. Twenty to thirty years after site abandonment, there is no visible difference between enclosure and regional sediments. Micromorphological, mineralogical, and phytolith analyses, of enclosure sediments, however, allow differentiation of enclosure from regional sediments. Our results show that a unique undulating microlaminated structure is distinctive of enclosure sediments. Enclosure sediments, especially small stock, also contain a rare mineral, monohydrocalcite ($\text{CaCO}_3 \cdot \text{H}_2\text{O}$). In addition, large amounts of opal ($\text{SiO}_2 \cdot n\text{H}_2\text{O}$), in the form of phytoliths, are found in enclosure relative to regional sediments. These differences are likely to be preserved in the archaeological record, and this approach will allow better understanding of the spread of pastoralism in Africa and elsewhere.

© 2002 Elsevier Science Ltd. All rights reserved.

Keywords: PASTORALISM; EAST AFRICA; ETHNOARCHAEOLOGY; MINERALOGY; MICROMORPHOLOGY; PHYTOLITHS; LIVESTOCK ENCLOSURES.

Introduction

The adoption of food production, and a new more intensive relationship with plant and animal resources, represents a major turning point in prehistory (reviews in Gebauer & Price, 1992; Price & Gebauer, 1995; Harris, 1996). The question of why and how this happened is one of the central questions in archaeology. In Africa, pastoralism is the earliest form of food production, preceding mixed agriculture by 4000 years (van der Veen, 1999; Blench & MacDonald, 2000; Marshall & Hildebrand, 2002). Pastoralists, mobile herders who move animals to water and pasture, are also known from many other areas of the world (Dyson-Hudson & Dyson-Hudson,

1980). In order to understand the earliest food production in Africa, and the spread of pastoralism elsewhere, it is important to be able to identify archaeological sites that were occupied by pastoralists, and distinguish them from those occupied by hunter-gatherers.

The archaeological problem

The identification of archaeological sites occupied by pastoralists is not always straight-forward. First, based on ethnographic observations, pastoralists tend to leave few material remains in their abandoned sites (e.g., Gifford, 1978; Robertshaw, 1978; Banning & Kohler-Rollefson, 1992). Second, many pastoral sites preserve only a few features (Robertshaw & Marshall, 1990; Mutundu, 1999). Third, interactions

*Corresponding author.

between pastoralists and hunter-gatherers or horticulturalists may result in ambiguous material remains in archaeological sites (elaborated below). The difficulty of distinguishing between hunter-gatherer and pastoral sites, in particular, causes a major interpretive problem in African prehistory.

In East Africa, prehistoric hunter-gatherer and pastoral groups (4000–2000 BP) have been most commonly differentiated based on distinctive lithic assemblages (Ambrose, 1984, 2001). Ceramics of the period, are believed to have been mostly produced by pastoralists (Ambrose, 1984; Gifford-Gonzalez, 1998). Interactions between hunter-gatherers and pastoralists are recognized archaeologically by the occurrence of mixed faunal assemblages (i.e. remains of wild and domestic taxa at the same site, as at Enkapune Ya Muto; Ambrose, 1998), and the presence of pastoral ceramics in hunter-gatherer sites (Ambrose, 1998; Gifford-Gonzalez, 1998). Due to these interactions, it is sometimes difficult to distinguish between sites that were occupied by hunter-gatherers and those occupied by pastoralists. In addition, where hunter-gatherer sites preserve domestic stock, it is difficult to know whether hunter-gatherers acquired these animals for immediate consumption or whether they are in the process of becoming herders (Marean, 1992). These problems are central to understanding the spread of food production, particularly in eastern and southern Africa (Bower, 1991; Marshall, 1990; Smith, 1992).

Pastoral groups live in open-air settlements that include fenced animal enclosures in order to protect their herds from nocturnal predators and from raiding by other humans (Kruuk, 1980; Marshall, 2000). In contrast, hunter-gatherer settlements do not include animal enclosures, unless the hunter-gatherers are in the process of adoption of pastoralism (Yellen, 1984; Mutundu, 1999). One strategy for identifying pastoral sites is to take advantage of the fact that in East Africa (and elsewhere) large amounts of dung accumulate in livestock enclosures (e.g., Gifford, 1978; Mbae, 1986; Lamprey & Waller, 1990). In open-air archaeological sites, however, dung, which is mostly composed of organic matter, degrades with time and is not readily identified. The major objective of this study, therefore, is to find durable indicators for livestock enclosures.

Previous research

Previous research dealing with identification of livestock dung is mainly limited to relatively rare deposits that preserve organic remains. Such studies include those of lipid biomarkers (e.g., Evershed *et al.*, 1997; Simpson *et al.*, 1998; Bull *et al.*, 1999), parasites in dung (e.g., Jones *et al.*, 1988; Schelvis, 1992), and micromorphology. Micromorphological studies mainly base the identification of dung deposits on the presence of organic fibres and structureless (amorphous) organic matter. Mineralogical components associated with the organic matter are also used. These include opal

phytoliths, calcium-oxalate druses, phosphate compounds, and in particular dung spherulites (Courtney *et al.*, 1991; Macphail & Goldberg, 1995; di Lernia, 1998; Boschian & Montagnari-Kokelj, 2000; Akeret & Rentzel, 2001; see also Brochier *et al.*, 1992). Wattez *et al.* (1990) identified a microlaminated structure in sediments from the cave of Arene Candide that is believed to be derived from herbivorous excrements.

Brochier (1983) emphasized that the association of spherulites and phytoliths is important for identifying ancient pastoral activities. Dung spherulites are calcareous spheres measuring 5–15 µm in diameter, that possess a spherulitic figure (i.e. a pseudo-uniaxial interference figure) when observed under crossed polarized light (Canti, 1997, 1998). Spherulites form in the guts of animals (Canti, 1999) and are excreted in their dung. Caprine dung is particularly rich in spherulites (Canti, 1998). Spherulites do, however, occur in the dung of other animal species, not all of them domestic (Canti, 1997, 1998; Goren, 1999). Brochier *et al.* (1992) note that spherulites do not preserve in open-air sites.

Phytolith morphologies have been used to distinguish cattle from sheep dung (Powers *et al.*, 1989). Elemental analyses (mainly phosphorous) have been used to identify activity areas within sites, but are not indicative of specific activities (e.g., Lillios, 1992; Sanchez *et al.*, 1996; see also Middleton & Price, 1996).

In this study we searched for durable indicators of livestock enclosure sediments by using a combination of techniques including micromorphology, mineralogy and quantitative phytolith analyses. All analyses were performed following geo-ethnoarchaeological fieldwork in southern Kenya.

Strategy

Fieldwork was conducted among the Kisongo Maasai of Kajiado District, near Rombo (Figure 1). The Kisongo Maasai are subsistence-oriented cattle, sheep and goat pastoralists. Their mode of pastoralism is semi-nomadic, taking advantage of seasonal pasture areas (Ryan *et al.*, 2000; on Maasai pastoralism in general see Dyson-Hudson & Dyson-Hudson, 1980; Galaty, 1981; Grandin *et al.*, 1989; Lamprey & Waller, 1990). A Maasai settlement, called boma (Swahili) or enkang (Maa), is made up of several independent polygamous families and their livestock. Settlements are laid out around a central livestock enclosure formed by encircling huts and thorn fences, and smaller enclosures for sheep and goats (i.e. caprines) and calves (Mbae, 1986; pers. obs., 1999; Figure 2). The huts are constructed from a mixture of ash, cattle dung and mud over a wooden frame (Andersen, 1978; pers. obs., 1999). Dung is never burned for fuel. Maasai settlements in general, and caprine enclosures in particular, contain thick dung deposits (pers. obs., 1999). Because contemporary Maasai pastoralists live under similar environmental conditions as prehistoric

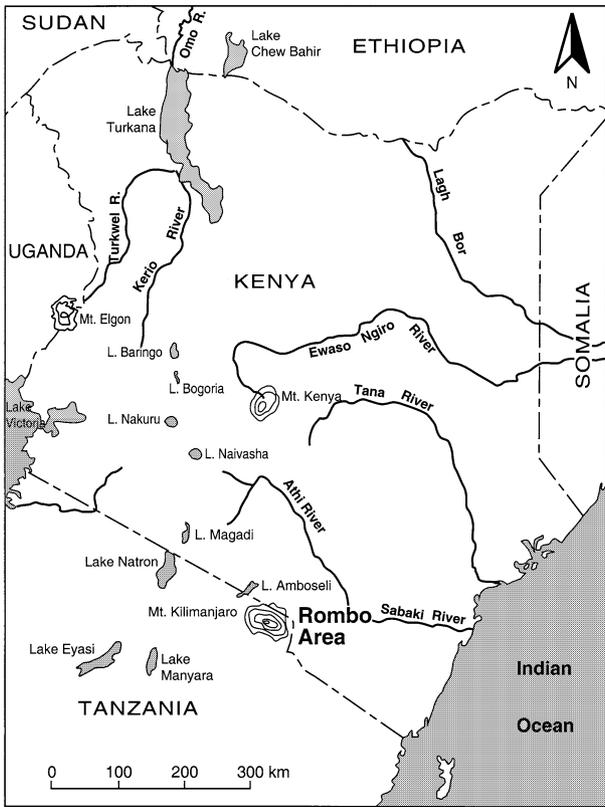


Figure 1. Map of Kenya showing the Rombo area (southern Kenya) where fieldwork was conducted.

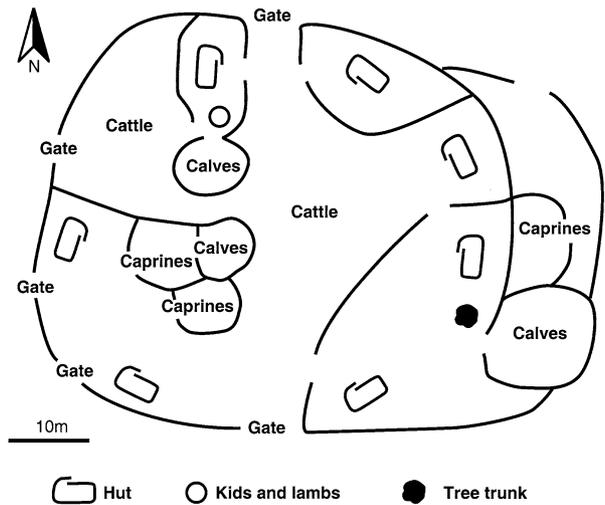


Figure 2. Sketch map of the inhabited boma (in 1999). This boma is occupied by four families, one of which is Ole Koringo's. At least one gate belongs to a married man. Married women build their huts next to their husband's gate. Note the cattle enclosure in the central part of the boma and the smaller enclosures for caprines and calves.

East African pastoralists, and herd the same domestic species, we expect that patterns of dung buildup in Maasai settlements are analogous to dung buildups in prehistoric pastoral sites.

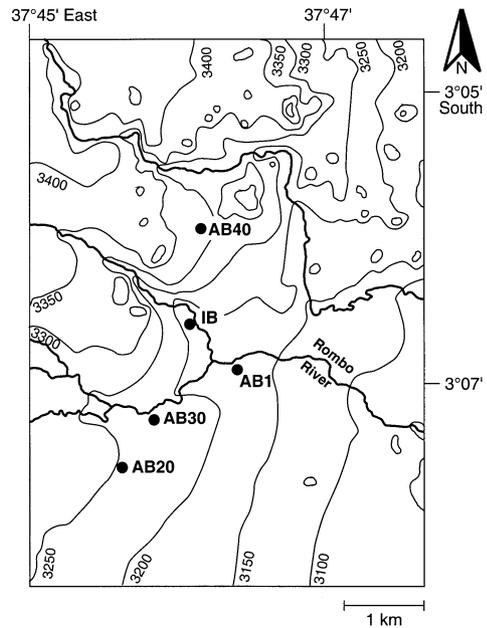


Figure 3. Topographic map of the study area showing the location of the inhabited (IB) and the four abandoned bomas (AB1 to AB40). Elevation contours are in feet.

Two seasons of fieldwork (May 1999, January 2001) oriented particularly towards obtaining sediment samples for further study, were conducted by one of us (R. S-G.) in collaboration with K. Ryan (MASCA, The University Museum of Archaeology and Anthropology, Philadelphia) and Dr Karega-Munene (National Museums of Kenya, Nairobi). Sediments from one occupied boma and four abandoned bomas were sampled, and compared to regional sediments outside bomas. The bomas sampled formed a taphonomic sequence, having been abandoned from one to 40 years prior to fieldwork. This allowed study of dung deposition and its decomposition through time.

Materials and Methods

Fieldwork

One inhabited boma and four abandoned bomas were located by a Maasai elder (Ole Koringo) with whom K. Ryan had previously worked. Ole Koringo's family had lived at these sites and he remembered being a child at one of them, living as an adult in two others, and a fourth where friends of his lived. All bomas are located at about the same elevation and within an area of 8 km² (Figure 3). Fifty to sixty head of cattle and 50–60 head of sheep and goats (caprines) are typically penned every night in bomas in the study area. The bomas were sketch-mapped using a compass and tape. The inhabited boma allowed for ethnographic observations to be made and the abandoned bomas provided an opportunity to study the taphonomy of the enclosure sediments. Information on the times of their

abandonment was estimated by Ole Koringo based on well-remembered events (such as initiations of age sets). This information was partly corroborated using air photographs obtained from the Surveys of Kenya.

The four bomas studied had been abandoned for approximately: 5 months (2 years in the 2001 season, hence termed AB1), 15–20 years (hence termed AB20), 30 years (hence termed AB30), and 40 years (hence termed AB40). Bomas in the study area were typically occupied for some 10–15 years. Abandonment of all sites was explained as due to “a need for change”, except for AB1 that was abandoned following flooding by the Rombo River in December 1998. According to Ole Koringo, none of the bomas was abandoned as a result of the dung deposits being too deep, or due to parasite infestations (contra [Western & Dunne, 1979](#)). In addition, none of these bomas was burned after abandonment (contra [Western & Dunne, 1979](#)).

Sampling locations within bomas included the central cattle enclosure and one or more caprine enclosures, identified by Ole Koringo. For comparison, at least two samples of regional sediment were collected several metres away from boma fences taking care not to sample gate areas where animals also deposit dung. Samples were collected through excavation of 1 × 1 m test pits. These were excavated to a depth of about 20 cm below the contact between enclosure sediments (i.e. dung) and the regional sediments (i.e. soil). This contact was fairly easily distinguishable in AB1 and AB20 (based on colour and structural differences such as lamination), but quite hard to discern visually in AB30 and AB40. Test pits for regional sediment sampling were dug to approximately 30 cm below surface. All test pits were photographed, and thicknesses of stratigraphic units were measured. Loose sediment samples from different layers (distinguished primarily by colour) were collected in plastic bags. In addition, block sediment samples were collected, some of them by using PVC pipes. Blocks were tightly wrapped with paper and masking tape.

Laboratory techniques

Embedded block samples were prepared following conventional procedures (e.g., [Courty *et al.*, 1989](#)). Thin sections were observed using a Nikon polarizing light microscope (Labophot2-pol) and described following [Bullock *et al.* \(1985\)](#) and [Courty *et al.* \(1989\)](#).

The pH of bulk sediment samples was measured using a pH-meter (Metrohm 654) after preparation of saturated solutions in water ([Thomas, 1996](#)).

Mineralogical identifications were performed on bulk samples using Fourier Transform Infrared (FTIR) spectroscopy (MIDAC Corp., Costa Mesa, CA, U.S.A.). Spectra were obtained by mixing about 0.1 mg of powdered sample with about 80 mg of KBr. Spectra were collected at 4 cm⁻¹ resolution (for more details see [Weiner *et al.*, 1993](#)).

In some cases when mineralogical identification by FTIR was difficult, X-ray powder diffraction (XRD) and Energy Dispersive X-ray spectrometry (EDS) techniques were also used. XRD spectra were collected with a Ru200 generator and a D-Max/B diffractometer (both of Rigaku Corp., Japan) operating with Cu anode at 40 kV and 120 mA. Scans were made between 2–60° 2-Theta at a scan speed of 1° per minute. Data were interpreted using the Jade 5 Data Analysis Software (Materials Data Inc., Livermore, CA, U.S.A.). Elemental analyses using the EDS technique were performed on either polished, uncovered, petrographic thin sections or on powdered samples mounted in Buehler Ultra-Mount and polished. The polished samples were carbon coated and analysed with a Jeol 6400 scanning electron microscope with an EDS Link (Oxford Instruments) operating system. Images were recorded in the back-scattered electron (BSE) mode.

Quantitative phytolith analyses were performed using [Albert *et al.*'s. \(1999\)](#) method, except that the acid treatment was done without heating, and organic matter in organic-rich sediments was removed by ashing (550°C for 4 h) prior to acid treatment. The samples were homogenized prior to analysis using a mortar and pestle. They were lightly ground in order not to break the phytoliths and sieved through a 0.5 mm sieve. The fraction smaller than 0.5 mm was used for counting. In contrast to [Albert *et al.* \(1999\)](#) who only counted opaline particles that clearly resemble phytoliths, in this study every opaline particle was counted. This includes particles as small as 2.5 µm that show a pinkish to purple colour under plane polarized light (PPL) and are isotropic under crossed polarized light (XPL). This approach was taken because grasses contain very small geometric shaped short cell phytoliths ([Mulholland & Rapp, 1992](#)). Counting was performed on 10 fields; 2 dense fields in the central area of the slide and 8 peripheral fields. This represents a weighted mean of the phytoliths on the slide. The counting was performed using a Nikon petrographic microscope (as above), at 400 × magnification.

Six samples, three from caprine enclosures and three from cattle enclosures were analysed for phytolith morphologies. More than 100 phytoliths with consistent morphologies were counted in each sample and divided into morphological groups (following [Albert & Weiner, 2001](#); [Mulholland & Rapp, 1992](#)).

Radiocarbon dating was performed on soil humates that were precipitated from four samples of regional sediments along a 1.5 m deep soil profile. The sediments were sampled from the following depths below surface: 5 cm, 40 cm, 90 cm and 150 cm. The soil samples were treated with 1 N HCl to dissolve inorganic carbonate, followed by extraction of humic acids with 0.1 N NaOH. The humic acids were precipitated after addition of 1 N HCl, washed and dried. The humics were burned to release CO₂ that was AMS dated. The samples and targets were prepared at the

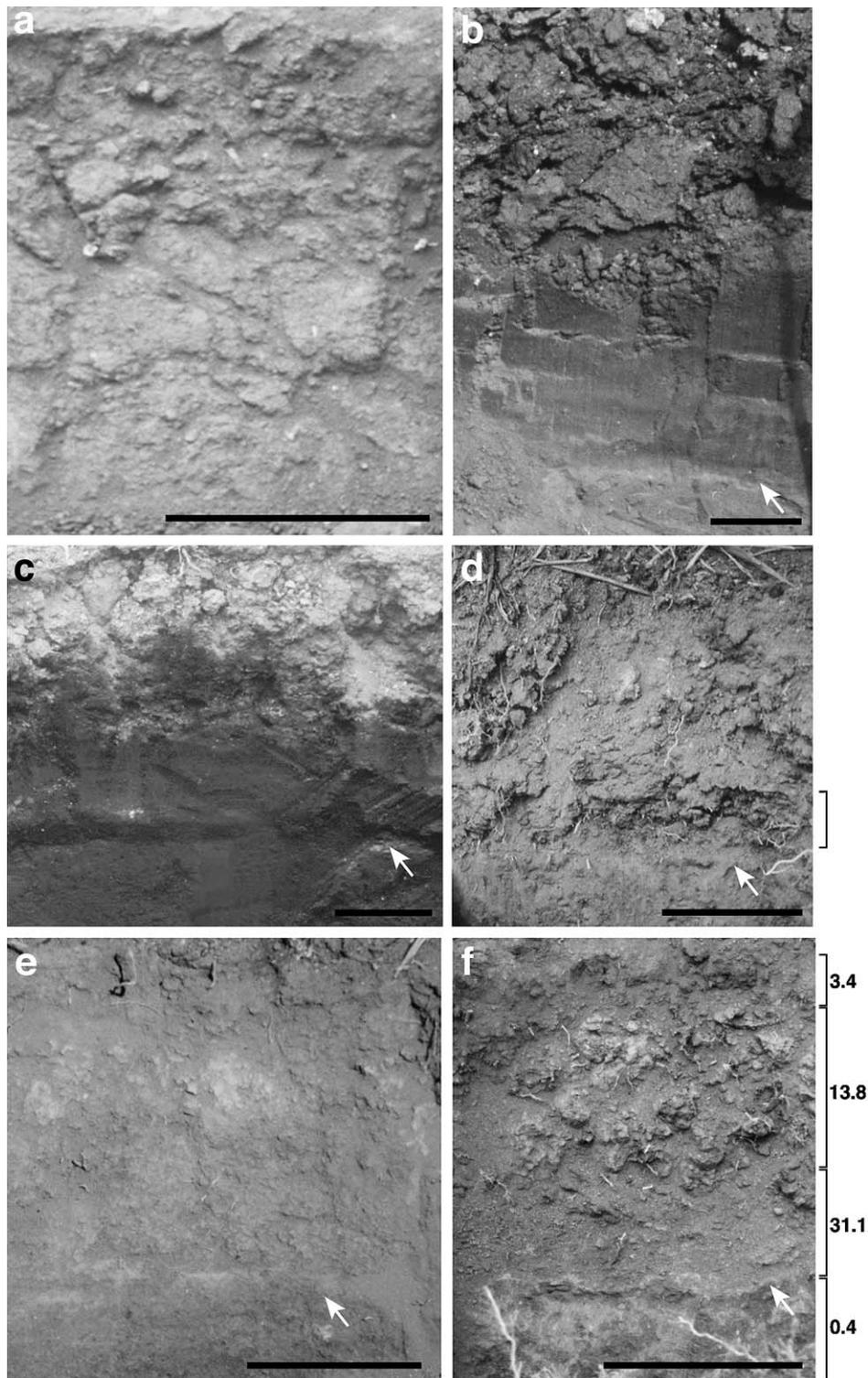


Figure 4. Photographs of sediment profiles in open test pits. (a) Regional sediment in the vicinity of the inhabited boma. (b) Organic-rich sediments from the cattle enclosure in AB1. (c) Sediments of a caprine enclosure in AB20. Note an upper oxidized, organic-poor, layer and an organic-rich layer below it. (d) Sediments of the cattle enclosure in AB20. Note laminated layer (bracketed) above compacted, hard, regional sediment. (e) Sediments in a caprine enclosure in AB30. There is no visual evidence of an organic-rich layer. (f) Sediments of the cattle enclosure in AB40. Note structural similarity of (e) and (f) to (a) and the absence of dark organic matter in (e), and (f). Arrows indicate the contacts between enclosure sediments and underlying regional sediments. Scale bar: 10 cm. Profile (f) is divided into an upper, post-abandonment, layer, two enclosure layers below it and a lower layer of compacted regional sediment. The numbers indicate phytolith concentrations in each layer (in millions per 1 g of total sediment). Note the distinct difference in phytolith concentrations between the underlying regional sediment and the enclosure sediments directly above it.

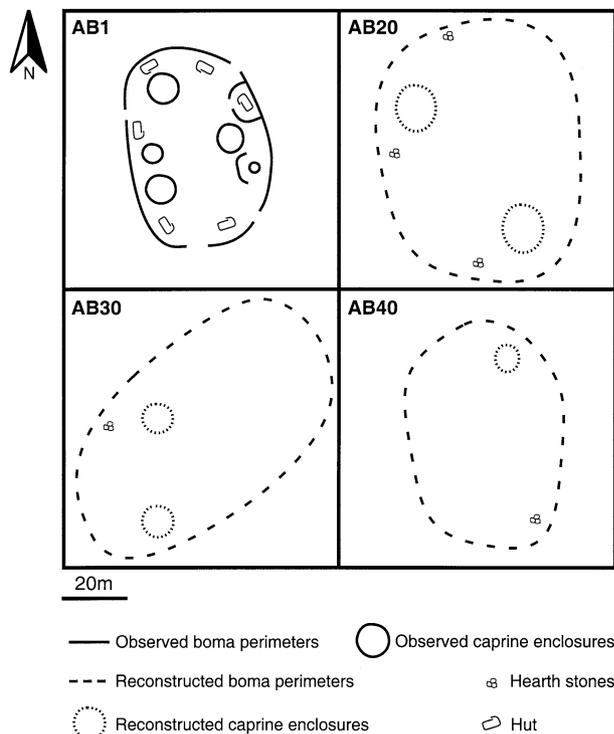


Figure 5. Sketch maps of the four abandoned bomas. In AB1 all features were mapped. In AB20, AB30 and AB40 only the caprine enclosures that were sampled are shown. Note that not all concentrations of hearth stones are drawn.

Radiocarbon Laboratory of the Weizmann Institute (Israel), and the analyses were performed at the University of Arizona, Tucson.

Results

We describe field observations first, followed by descriptions of the sediment micromorphology, mineral composition and finally phytolith contents and morphologies. In each section we compare the analyses of the enclosure sediments to those of regional sediments.

Field observations

Regional sediments. Soils in the Rombo area developed on Kilimanjaro Pleistocene basalts. They are brown or red clays that are relatively fertile, have good drainage, and contain calcite accumulations in the lower soil horizons (Touber, 1983). No stratigraphy was observed at the depths dug in this study (Figure 4a), except for an upper finely stratified layer in the AB1 location. No visible organic matter was noted.

Abandoned bomas and their enclosure sediments. The recently abandoned boma, AB1, was similar in structure to the inhabited boma; huts, fences and enclosures were well preserved (Figure 5a). All other bomas were

so degraded that they could not be identified except by someone from the area. No features could be observed, except for occasional hearthstones (see Figure 5b–d).

In AB1, occupied for approximately 15 years, maximal thickness of sediments deposited in the enclosures were less than 1 m in the cattle area, and more than 1 m in the caprine enclosures. Overall, it was noted that dung accumulation in cattle enclosures is relatively flat, while in caprine enclosures it forms heaps (Figure 6). Enclosure sediments were organic-rich, wet (oozing), with thick massive black layers (Figure 4b).

In AB20, one caprine heap was still somewhat visible, with a total thickness of 30 cm. The profile was divided visually into an upper white blocky layer (10 cm), a black-brown massive mottled layer (10 cm), and a massive black layer (10 cm), overlying the brown regional sediment (Figure 4c). The profile of the cattle enclosure sediments was *c.* 15 cm thick, with an upper layer of crumbly sediment (up to 10 cm) overlying a yellow to black-brown (2–7 cm) laminated layer (Figure 4d).

In AB30 and AB40, enclosure sediment profiles were quite thin (from 3 cm to 18 cm), and uniformly organic-poor. Layers with slightly different shades of gray and brown were occasionally observed and it was not clear which of these layers had previously contained dung. In addition, the contact between the assumed enclosure sediments and the regional sediment below was often visually unclear (Figure 4e–f).

Overall, enclosure sediment profiles observed in test pits tend to thin with time and lose their distinctive black (organic) colour after 20 to 30 years.

Average pH measurements

Average pH measurements show that regional sediments are slightly alkaline (7.6 ± 0.24 , $n=13$). Organic-poor enclosure sediments are even more alkaline (8.0 ± 0.39 , $n=10$) and organic-rich enclosure sediments are highly alkaline (8.8 ± 0.57 , $n=10$). Regional sediments underlying enclosure sediments are more similar to organic-poor enclosure sediments than to regional sediments (8.1 ± 0.75 , $n=9$).

Micromorphology

Table 1 summarizes the micromorphological observations of regional and enclosure sediments. It includes descriptions of the microstructure, the fine fraction, and the distribution of the coarse fraction with respect to the fine fraction, termed related distribution. In all samples, the coarse fractions are similar in composition, sorting, and roundness. Therefore, the coarse fraction is described only once, in the regional sediments section. The notes section includes descriptions of secondary features. Terminology follows Bullock *et al.* (1985).

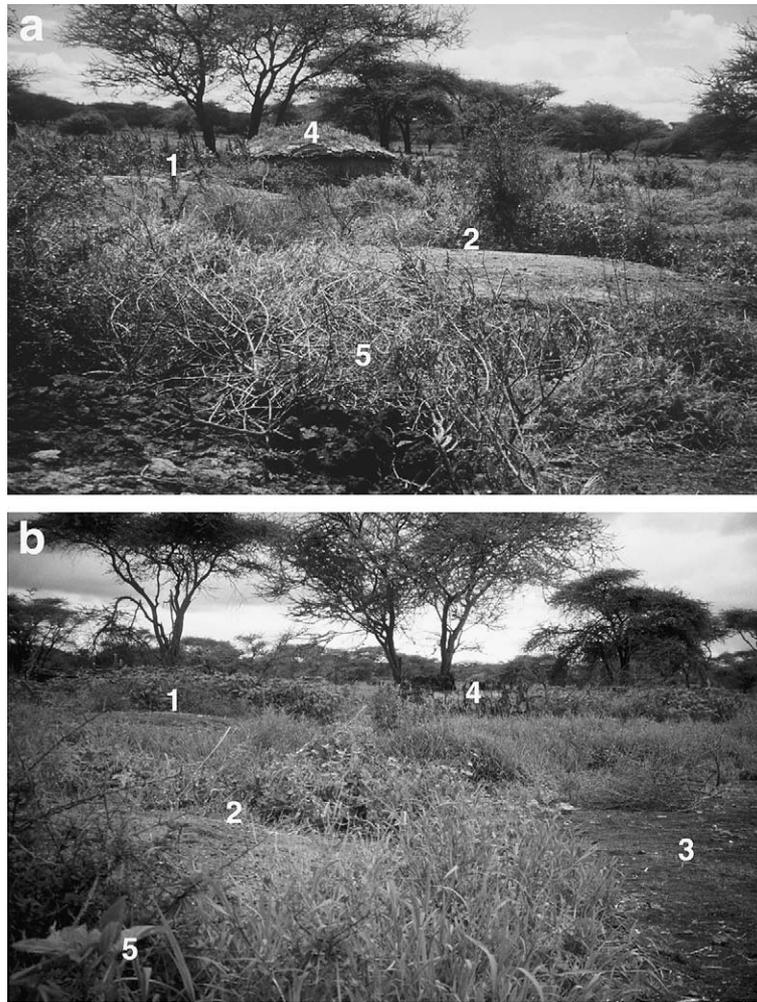


Figure 6. Photographs of AB1 in May 1999 (a) and January 2001 (b). Note two caprine enclosures (elevated heaps, marked 1 and 2) and main cattle enclosure (flat, marked 3). A hut (4) observed in 1999 collapsed by 2001 and thornbush fences (5) observed in 1999 partially disintegrated in 2001. Fenced areas, where dung was not accumulating in large quantities, are marked by grass growth in 2001. Field of view: approximately 20 m.

Regional sediments. The five embedded blocks prepared from sediments outside boma perimeters are all similar (i.e. controls; [Figure 7a–b](#)). They are composed of clay, grains of basalt and basalt-derived minerals (i.e. feldspars, pyroxenes and iron oxides, the latter being weathering products) and occasional pedogenic carbonate nodules. The basalt and basalt-derived grains are randomly distributed in the clayey groundmass (i.e. a porphyric related distribution). The fine fraction is not oriented (i.e. an undifferentiated birefringence, or, b-fabric). Microstructures observed include poorly developed angular blocky, granular and crumbly structures. The upper part of the sediments from AB1 shows laminated and crack structures with some carbonate impregnation of the micromass and along voids. These features result from flooding of the site by the Rombo River.

Enclosure sediments. AB1: Sediments from both cattle and caprine enclosures are dominated by organic

material that includes vegetal fibres and other recognizable plant tissues. The overall macroscopic structure is platy ([Figure 7c](#)). Planar voids are dominant with traces of infilling by acellular decomposed organic matter. The microstructure is laminated ([Figure 7d](#)). The fine fraction is mostly acellular organic matter that surrounds the coarse fraction or forms braces that link the coarser units (termed chitonic and gefuric related distributions, respectively; [Table 1](#)). The fine fraction may contain spherulites. They are more abundant in caprine enclosure sediments than in cattle enclosure sediments. The spherulites and other carbonatic forms appear as birefringent areas in the groundmass (i.e. a crystallitic b-fabric; e.g., [Figure 8c](#)). The upper few centimetres in the regional sediment below the organic-rich sediments is compacted due to livestock trampling and has accumulations of carbonates in and along voids ([Figure 7e–f](#)). These sometimes also impregnate the clayey groundmass. This compacted structure was observed in all sampled profiles that

Table 1. *Micromorphological descriptions of regional and enclosure sediments. Refer to text for terminology*

Context (sample nos)	Microstructure	Related distribution	Fine fraction	Notes
Regional sediments Representative (KEN-19, 31, 133, 181, 225)	Mostly granular and crumb with compound packing voids. Also poorly developed angular blocky structure. Other voids are vughs, chambers and channels.	Open to closed porphyric.	Light to dark brown clay with undifferentiated b-fabric.	Coarse fraction (c. 10–20% by area, of sediment) includes 20 µm to 4 mm grains of basalt, feldspars and olivine, poorly sorted and angular. Occasional pedogenic carbonate nodules (up to 200 µm), slug skeletal granules and possible earthworm organic casts (up to 300 µm). Crack and platy microstructure at top of samples 31 and 181 due to flooding event, together with crystalline b-fabric (carbonate probably originates from within boma sediments).
Cattle enclosure profiles AB1 (KEN-25)	Upper (7 cm): Compacted organic matter. Platy structure, planar voids, some vughs and channels. Laminated microstructure. Middle (7.5 cm): Bioturbated, granular structure, compound packing voids and vughs.	Porphyric.	Dark brown organic matter, mostly undifferentiated b-fabric, areas of crystalline b-fabric.	Few dung spherulites. Vegetal matter (50 µm to 6 mm long particles) forms the main part (~30%) of the coarse fraction. Large passage features.
	Lower: Compacted regional sediment, sub-angular blocky and crumb structures. Planar and compound packing voids, some channels and cracks. Upper (divided into layers a and b): Layer a (1.7 cm): Net-like spongy structure, vughs and chambers.	Porphyric.	Dark brown to black clay with possible organic staining. Undifferentiated and crystalline b-fabrics.	Few organic fibres, mostly in the upper 2–3 cm. Many mineral grains appear to be in a process of alteration/dissolution. Areas of clayey groundmass impregnated by carbonate.
AB20 (KEN-42, 43, not oriented; KEN-108)	Layer b (1.2 cm): Platy structure, planar voids. Lower: Compacted regional sediment, sub-angular blocky and bridged/pellicular ped structures. Compound packing and planar voids, vughs and channels.	Gefuric.	Brown clay, crystalline and undifferentiated b-fabrics.	Highly fragmented, decomposed, vegetal matter (up to 1.2 mm long). Few organic coprolites. Phytoliths comprise about 20% of fine fraction. Small areas contain few dung spherulites. Phytoliths comprise about 30–50% of the fine fraction. Vegetal fibres comprise about 20% of coarse fraction.
		Closed porphyric.	Grey, yellow and brown, clay, carbonate and organic matter. Crystalline b-fabric.	Some voids coated with carbonate, few with clay.
			Light to dark brown clay and carbonate, undifferentiated and crystalline b-fabrics.	

Table 1. Continued

Context (sample nos)	Microstructure	Related distribution	Fine fraction	Notes
AB30 (KEN-53, 224)	Upper: Post abandonment sediment, granular structure. Middle (4 to 13 cm): Decomposed enclosure sediment, angular to sub-angular blocky structure, granular and/or crumbly at places. Planar and compound packing voids and vughs. Faint microlaminated undulating structures. Lower: Compacted regional sediment (~4 cm) and below it regional sediment.	Porphyric. Open porphyric.	Light to dark brown clay, undifferentiated b-fabric. Shades of brown and black, clay and small fragments of organic matter. Crystallitic b-fabric due to organics.	Root action? Large amount of phytoliths. Areas of laminar arrangement of black organic particles. Few carbonate nodules.
AB40 (KEN-69)	Upper (5 cm): Highly fragmented granules (~0.5 mm in diameter) of enclosure sediment in sub-angular blocky and granular structures. Planar and compound packing voids, channels, cracks and vughs. Distinctive microlaminated undulating structures. Lower: Moderately fragmented granules (~6 mm in diameter) of enclosure sediment in sub-angular blocky structure. Planar voids dominate. Distinctive microlaminated undulating structures.	Closed porphyric. Open porphyric.	Light to dark brown clay and carbonate, undifferentiated and crystallitic b-fabrics. Grey, orange, brown clay, organics, opal and carbonate. Crystallitic b-fabric due to organics.	Little carbonate infilling/impregnation of voids/groundmass. Root action?
Caprine enclosure profiles AB1 (KEN-22)	Vegetal matter in a platy and sub-angular blocky structures, planar voids dominate but also vughs, channels and simple packing voids.	Open Porphyric. Chitonic-gefuric.	Grey, orange, brown clay, organics, opal and carbonate. Crystallitic b-fabric due to organics. Orange-coloured organic and possibly organo-metallic matter and dung spherulites, crystallitic b-fabric.	Few dung spherulites, few carbonate nodules, slug skeletal granules and possible earthworm casts. Voids coated with amorphous organic matter. Large passage features. Few Ca-oxalate druses. Many phytoliths.

Table 1. Continued

Context (sample nos)	Microstructure	Related distribution	Fine fraction	Notes
AB20 (KEN-33, 39, 104)	Upper (13 cm): Mostly inorganic with complex microstructure including angular blocky, vuggy and crumb structures. Peds appear to be composed of welded domains of carbonate, opal and organic matter, with distinctive microlaminated undulating structures. Other structures are net-like and opaline laminae/"pockets". Large planar voids, channels, chambers and vughs. Middle (10 cm): Mostly organic with complex microstructure including angular blocky, platy and spongy structures. Large planar voids, vughs and simple packing voids between vegetal fragments. Lower: Mostly regional sediment. Upper part is a mixture of regional sediment with vegetal matter, lower part is compacted regional sediment. Microstructure includes compacted granular structure and platy at places, but also crumb and spongy in the mixed upper part. Compound packing voids and vughs.	Upper, almost completely mineral: open porphyric. Lower, containing some vegetal matter: gefuric/chitonic.	Grey to yellowish brown and few black areas, composed of carbonate, organic matter, opal and clay. Crystallitic b-fabric.	Large (~ 1–2 µm) carbonatic crystals, also carbonatic pedogenic nodules. Few large vegetal fibres and seed coat fragments (up to 1.5 mm long) in the upper part, but about 40% of fibres, seed coats and other plant tissues (up to 8 mm long) in lower part. The organic matter in the lower part is moderately well preserved (orange to brown in PPL, orange to black in XPL). Few Ca-oxalate druses.
		Gefuric/chitonic.	Dung spherulites comprise most of the fine fraction, with some carbonate and amorphous organic matter. Crystallitic b-fabric.	Vegetal matter in good state of preservation (i.e., high birefringent colours in XPL).
		Closed porphyric.	Brown clay, crystallitic and undifferentiated b-fabrics.	Carbonate impregnation of groundmass and void coatings. Areas of carbonate capping/crusts.

Table 1. Continued

Context (sample nos)	Microstructure	Related distribution	Fine fraction	Notes
AB30 (KEN-48, 223)	Upper (16 cm): Granular and sub-angular blocky structures, compound packing and planar voids and vughs. Few peds show microlaminated undulating structures.	Porphyric.	Grey, yellow, orange and brown clay and silt, including carbonate and opal. Crystallitic b-fabric but also areas of striated b-fabric where organic fibres preserve.	Dung spherulites are rare and microlaminated undulating structures are faint. Large passage features and some organic casts. Few areas impregnated with carbonate. The frequency of peds larger than 1 mm in diameter rises below 5 cm depth. Overall, enclosure sediment is poorly preserved.
	Lower: compacted regional sediment. Platy and sub-angular blocky structures.	Closed porphyric.	Brown clay, undifferentiated and crystallitic b-fabrics.	Carbonate impregnation mostly along voids.
AB40 (KEN-63)	Angular blocky structure, granular or platy at places. Planar and compound packing voids and vughs. Distinctive microlaminated undulating structures.	Open porphyric.	Brown, grey, orange and restricted areas of greenish yellow, clay, carbonate, opal and organic matter. Crystallitic b-fabric due to large amounts (>50%) of dung spherulites.	Carbonatic and organic staining, also a few pedogenic carbonate and phosphate nodules. Few Ca-oxalate druses. Possible earthworm casts and a possible dung beetle pellet (rounded, c. 2 cm in diameter, made of very well preserved vegetal matter). Peds are more fragmented at the upper 6 cm of the profile and packed in a sub-angular blocky structure, while below 6 cm depth, peds are larger and arranged in a blocky-platy structure.

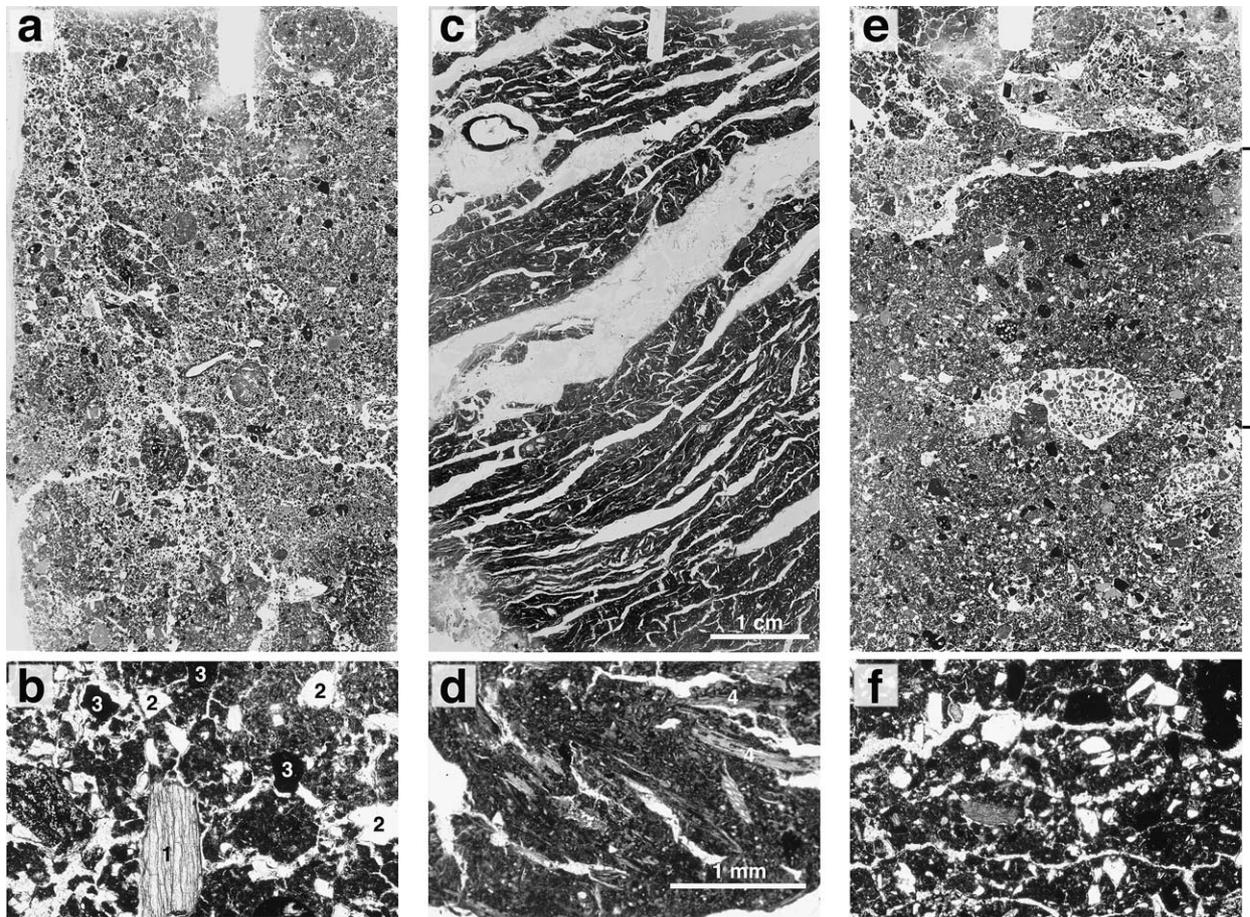


Figure 7. Photographs of thin sections (a, c, e) and representative photomicrographs (b, d, f) of areas in these thin sections. The scale bar in (c) applies to (a) and (e). The scale bar in (d) applies to (b) and (f). (a) Regional sediment outside AB20 (sample KEN-133). Note granular structure and angular blocks. (b) Photomicrograph of same sample in PPL. Note pyroxene grain (1), feldspar grains (2) and overall granular/crumb structure. Opaque grains are iron oxides (3). (c) Organic-rich enclosure sediment from AB1 (sample KEN-25a). Note platy structure. (d) Photomicrograph of same sample in PPL. Note vegetal fibres (4) forming a microlaminated structure. (e) Compacted regional sediment underlying caprine enclosure sediments in AB20 (sample KEN-104b). Note platy appearance of compacted area (bracketed, c.f., Fig. 7a) (f) Photomicrograph of the compacted area from the same sample, in PPL. Note compressed granules and planar voids in the overall platy structure (c.f., Fig. 7b). Groundmass and voids are impregnated and infilled with carbonate.

included regional sediments overlain by enclosure sediments (Table 1).

AB20: The upper parts of the caprine enclosure sediments from AB20 are organic-poor and are mostly carbonatic with a complex microstructure (described below). Spherulites are very abundant throughout the enclosure sediment profile. The middle part of the profile is still rich in organic matter. The lowermost part of the caprine enclosure sediment is a mixture of organic matter and regional sediment.

The cattle enclosure sediments in AB20 are disturbed by root action in their upper 15 cm. Below the root affected sediment, there is a laminated layer of organic-rich enclosure sediments. The organic matter is in a poor state of preservation, indicated by its low birefringence.

In the organic-poor enclosure sediments in AB20 we first observed a microlaminated undulating structure that characterizes degraded enclosure sediments

(Figure 8a). This structure is composed of alternating laminae of acellular organic matter and opal phytoliths. The laminae are about 10–30 μm thick, and are on the average continuous for distances up to 2 mm, and generally meandering (i.e. not straight). This structure is not mentioned in Bullock *et al.* (1985), and may be similar to a structure observed by Watzel *et al.* (1990) but not elaborated on. Based on the micro-morphological observations of the taphonomic sequence described in this study, we agree with Watzel *et al.* (1990) that the microlaminated structure results from trampling by livestock. Such trampling promotes re-organization of plant fibres found in herbivorous dung to form a platy macrostructure, sub-parallel to the sediment surface. Furthermore, we suggest that the undulations result from volume changes due to the degradation of organic matter, although phytoliths and small quantities of acellular organic matter are still preserved.

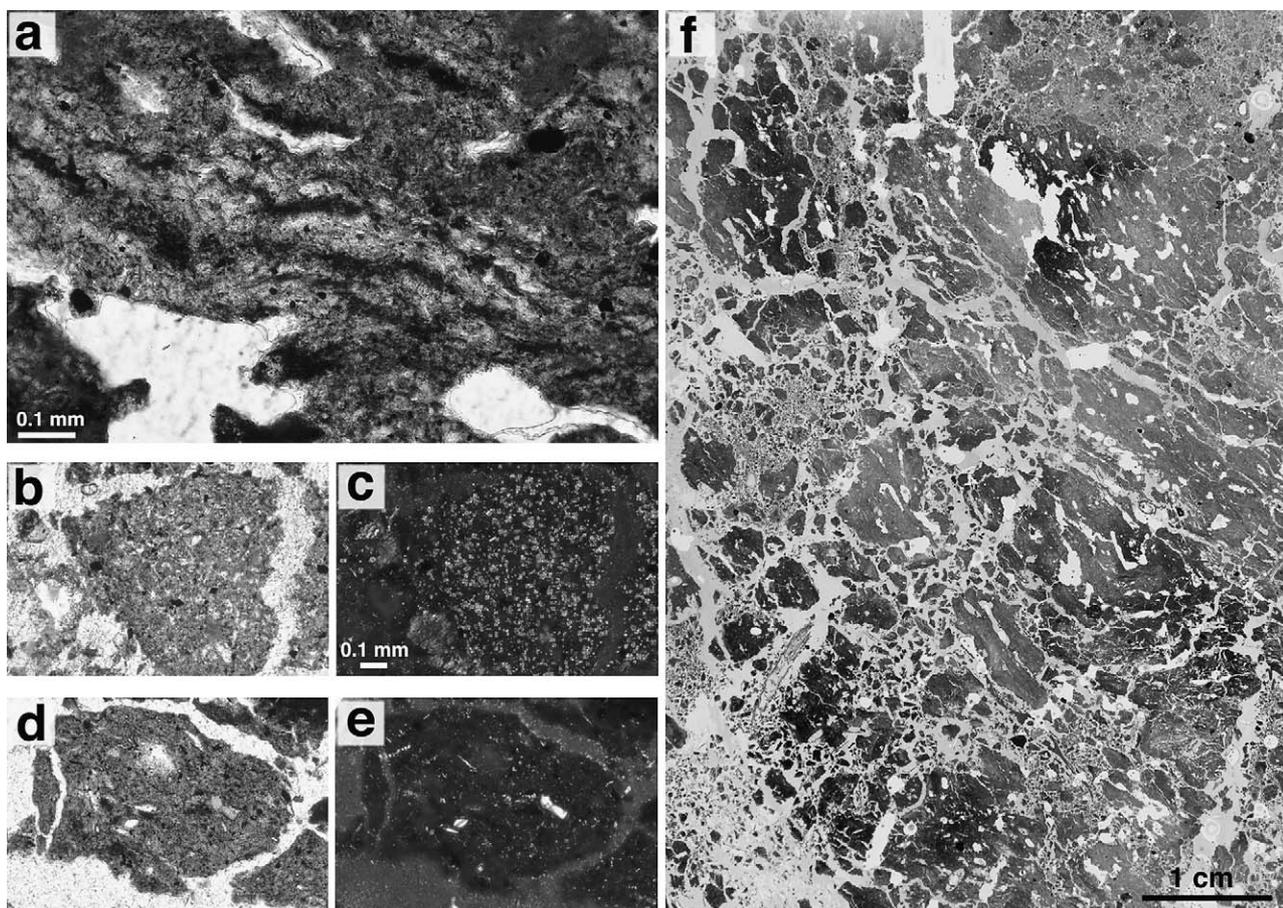


Figure 8. Organic-poor caprine and cattle enclosure sediments. (a) Photomicrographs of an “undulating” microlaminated structure in organic-poor caprine enclosure sediments from AB20 (sample KEN-39). Note alternating micro-layers of opal (transparent) and degraded organic matter (opaque). Overall groundmass in carbonate. (b) Photomicrograph from sample of caprine enclosure sediment from AB40 (KEN-63) in PPL and (c) in XPL. Note dung spherulites appear as birefringent granules in (c). (d) Photomicrograph of cattle enclosure sediment AB40 (sample KEN-69b) in PPL and (e) in XPL. Note that in comparison with the caprine enclosure sediment (b and c), there are fewer birefringent area in the cattle enclosure sediment under XPL. In both cases, the opaque groundmass in XPL is mostly isotropic composed of large numbers of opal phytoliths. (f) Photograph of thin section of caprine enclosure sediment in AB40 (sample KEN-63c). Note sub-angular blocky, granular and platy structures.

AB30: Enclosure sediments could be identified by the presence of isolated pockets of the undulating microlaminated structure. Hence enclosure sediments could be pinpointed. The sediments did not include many carbonate minerals, and spherulites were rare in the caprine enclosure sediments.

AB40: Cattle and caprine enclosure sediments from AB40 are similar in their structure and textures but differ in their mineralogical composition (Figure 8b–e). They have an overall angular to sub-angular blocky structure with areas of granular or platy structures (Figure 8f). Both show the characteristic microlaminated undulating structure. The difference between them is that the caprine enclosure sediments contain large amounts of carbonates, especially in the form of spherulites, when compared to the cattle enclosure sediments (cf. Figure 8b–c with Figure 8d–e). Due to the high frequency of opal phytoliths in both types of enclosure sediments, they

appear to be isotropic in XPL (Figure 8e), except for the high birefringence of carbonate minerals and some preserved organic fibres (Figure 8c, e). Secondary features include a few yellow and green (as observed in PPL) pedogenic phosphatic nodules that are isotropic in XPL.

Mineralogical characterization of bulk samples

Table 2 shows the minerals present in regional and enclosure sediments. Regional sediments in the study area are largely composed of clay minerals (Figure 9a). The XRD patterns of several samples show that clays are mostly of the kaolinite group. Vermiculite is probably also present. EDS analyses show that Si and Al are the major components in the clay mixture (Si constitutes 19–27% and Al constitutes 11–18%). Minor components include Mg and Na (1–2% each), and also P, K and Ca (usually less

Table 2. Minerals present in regional and enclosure sediments. The average weight % of the acid insoluble fraction (AIF) is shown for each category

Category	Sub-category	Major components	Minor components	Average weight % of AIF
Regional sediments		Clay (kaolinite).	Vermiculite, plagioclase, olivine, iron oxides, sodium nitrate, possible carbonates, opal, unidentified peaks at 1010, 754 and 746–8 cm ⁻¹ .	89.3 ± 5.87 (n=15)
Cattle enclosure sediments	Organic rich	Clay, organic matter.	Monohydrocalcite.	67.1 ± 21.55 (n=3) After ashing: 46.1 ± 0.07 (n=2)
	Organic poor	Clay, opal.	Monohydrocalcite, organic matter.	82.8 ± 9.81 (n=16)
Caprine enclosure sediments	Organic rich	Clay, monohydrocalcite, ammonium sulfate, organic matter.	Mg-rich calcite, unidentified peaks at 1155, 754 and 615 cm ⁻¹ .	55.6 ± 16.92 (n=5) After ashing: 32.6 ± 11.95 (n=4)
	Organic poor	Clay, monohydrocalcite, opal, Mg-rich calcite.	Organic matter, possible Ca-oxalate, unidentified peaks at 879, 688 and 574 cm ⁻¹ .	71.3 ± 15.34 (n=11)
Overlain regional sediments		Clay.	Carbonate, opal, sodium nitrate, unidentified peaks at 688 and 754 cm ⁻¹ .	87.0 ± 6.36 (n=14)

than 1% each). Also present are Fe-Ti oxides that are included in the clayey groundmass (Fe constitutes 8–12% and Ti constitutes 1–2%). Based on EDS analyses, feldspars observed in the micromorphological thin sections belong to the plagioclase group. The presence of the pyroxene diopside (CaMgSi₂O₆) was also inferred using the EDS.

Organic-rich enclosure sediments are composed of a mixture of clay, monohydrocalcite (CaCO₃ · H₂O), organic material and its decomposition products, notably ammonium sulfate (Figure 9b). Monohydrocalcite is found in higher concentrations in caprine compared with cattle enclosure sediments (Table 2).

Organic-poor enclosure sediments are composed mainly of clay and opal (Figure 9c) and most caprine enclosure sediments include monohydrocalcite as well. Some samples contain Mg-rich calcite (Figure 9d). EDS analyses of the phosphatic nodules observed in the oldest enclosure sediments yielded a non-stoichiometric ratio of Ca and P of 1:16, suggesting that the mineral is either amorphous Ca-phosphate or a non-stoichiometric dahllite (Ca₅(PO₄CO₃)₃(OH)) (LeGeros, 1991).

Quantitative phytolith analyses

Phytolith preservation is an important issue in alkaline soils, as opal solubility increases with elevated pH (Karkanis *et al.*, 2000). Many of the phytoliths studied seem to be weathered, as indicated by their fragmentary nature and pitted surfaces. In order to

determine whether or not phytoliths may preserve for long periods of time even in these alkaline soils, a fresh soil profile of 1.5 m was exposed on the bank of a small creek draining into the Rombo River. Figure 10 shows the number of phytoliths per gram of total sediment along this profile and the radiocarbon dates obtained from some of these samples. As there is no significant reduction in phytolith concentrations with increasing depth (i.e. age) we conclude that phytoliths can preserve for thousands of years in these alkaline sediments. The 1180 ± 40 BP (uncalibrated) age obtained for the sample from 5 cm below surface probably indicates the removal of the more recent part of the profile by river action, thus exposing a paleo-surface.

The overall error in phytolith concentrations was calculated as the % standard deviation between duplicated or triplicated samples. For homogenized samples it is ± 29% (n=5). This incorporates ± 9% (n=3) error in counting, calculated by counting the same slide twice. The remaining 20% is due mainly to weighing errors and loss of material during the heavy liquid separation procedure.

A consistent pattern was observed in the relative weights of the six fractions produced during the heavy liquid separation procedure (Figure 11). In enclosure sediments most of the material is concentrated in the 5th and 6th fractions (i.e. the light fractions containing mostly opal and organic matter), whereas in regional sediments most of the material is concentrated in the 1st through 3rd fractions (i.e. denser fractions containing mostly feldspars and clay).

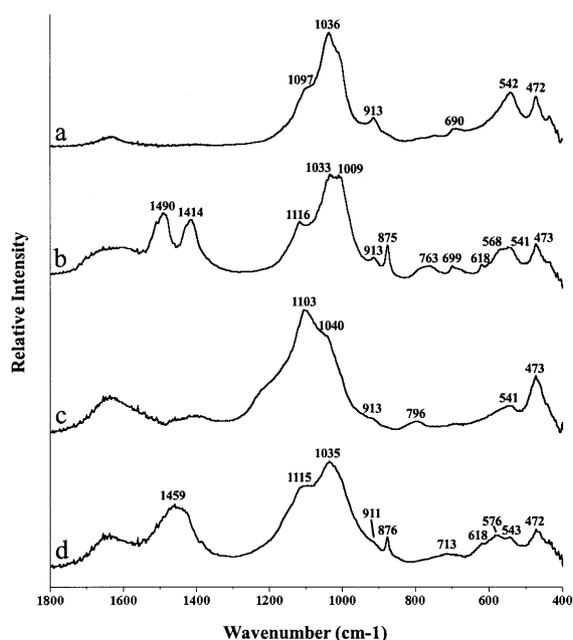


Figure 9. FTIR spectra of (a) Representative regional sediment composed almost entirely of clay (the peaks at 1097 and 690 cm^{-1} are from an unidentified material). (b) Organic-rich sediment from a caprine enclosure sampled in ABI. The peaks at 1116 and 618 cm^{-1} are from ammonium sulfate. Monohydrocalcite, characterized by the split between 1490 and 1414 cm^{-1} , produces the peaks at 875, 763, 699 and 568 cm^{-1} . The broad absorption around 1600 cm^{-1} is due to organic matter. The rest of the peaks are from clay (cf. Fig. 9a) and an unidentified material in 1009 cm^{-1} . (c) Laminated sediment from the cattle enclosure in AB20. Opal is the main component of this sample (peaks at 1103, 796 and 473 cm^{-1}). The sample also contains clay and organic matter. (d) Organic-rich sediment from a caprine enclosure sampled in AB20. The lack of splitting in the 1400 cm^{-1} region, together with the peak at 876 cm^{-1} and the weak and broad absorption centred around 713 cm^{-1} indicates that the mineral is Mg-rich calcite. It is probably in the process of recrystallization from monohydrocalcite. The sample also contains clay, organic matter and ammonium sulfate. The peak at 576 cm^{-1} is from an unknown material.

Phytolith concentrations from enclosure and regional sediments are shown in Figure 12. Concentrations in regional sediments are all lower than 10 million phytoliths per 1 g sediment and their range is quite restricted. The majority of samples have less than 4 million phytoliths per gram sediment. On the other hand, concentrations in enclosure sediments average more than 20 million phytoliths per gram sediment. The range of concentrations is very large and does overlap with that of the regional sediments.

Morphological analyses of phytoliths from cattle and caprine enclosure sediments show that they are indistinguishable (Figure 13). Almost all phytolith forms observed belong to grasses. Phytolith morphologies are therefore not useful for differentiating between cattle and caprine enclosures.

Discussion

This study shows that sediments from open-air animal enclosures in Maasai pastoral sites can be differenti-

ated from surrounding sediments, even 40 years after abandonment, by using a suite of analytical techniques that characterize the structure, mineralogy and phytoliths of sediments.

Structural indicators of enclosure sediments

Modern enclosure sediments are composed of large quantities of organic matter and small amounts of biogenically produced materials (i.e. spherulites, phytoliths). They can be visually distinguished from regional sediments by their black colour and laminated structure. Based on field observations, however, enclosure sediments cannot be visually differentiated from regional sediments 20 to 30 years after site abandonment, because the organic matter disintegrates as a result of oxidation. Detailed examinations of thin sections confirm that only very small amounts of organic matter are preserved 30 years after site abandonment. The bulk of the organic-poor enclosure sediments are composed of concentrations of the biogenic minerals included in dung, together with clay. These contribute to an overall texture that is finer grained in enclosure than in regional sediments, an observation also made by Brochier *et al.* (1992).

The platy structure characteristic of trampled organic-rich enclosure sediments may be preserved in organic-poor enclosure sediments. However, in most cases it is lost at the macroscopic level, due to root action and bioturbation. This results in a blocky to granular structure that is similar to that of regional sediments. Microscopically, however, the lamination is transformed into the unique microlaminated undulating structure, which can be observed even in the oldest enclosures examined. It is this feature that allows us to differentiate the base of the enclosure sediments from underlying regional sediments. In addition, we note that the underlying regional sediment appears to be compacted due to trampling.

Overall, the structural indicators for organic-poor enclosure sediments are microlaminated undulating structures, a texture that is finer grained than in regional sediments, and the presence of compacted structures in the regional sediments underlying enclosure sediments.

Mineralogical indicators of enclosure sediments

The biogenic minerals (carbonates and opal) present in small amounts in fresh dung are concentrated with time as organic matter is degraded. Carbonates appear in the form of spherulites and of calcite impregnating the groundmass and infilling voids. Opal is found in the form of phytoliths, mostly from ingested grasses. The mineral monohydrocalcite, a relatively unstable form of calcium carbonate, was identified, mainly in caprine enclosures. Its preservation is probably due to the alkaline nature of the sediments in the study area. Because of its high solubility it would not be expected

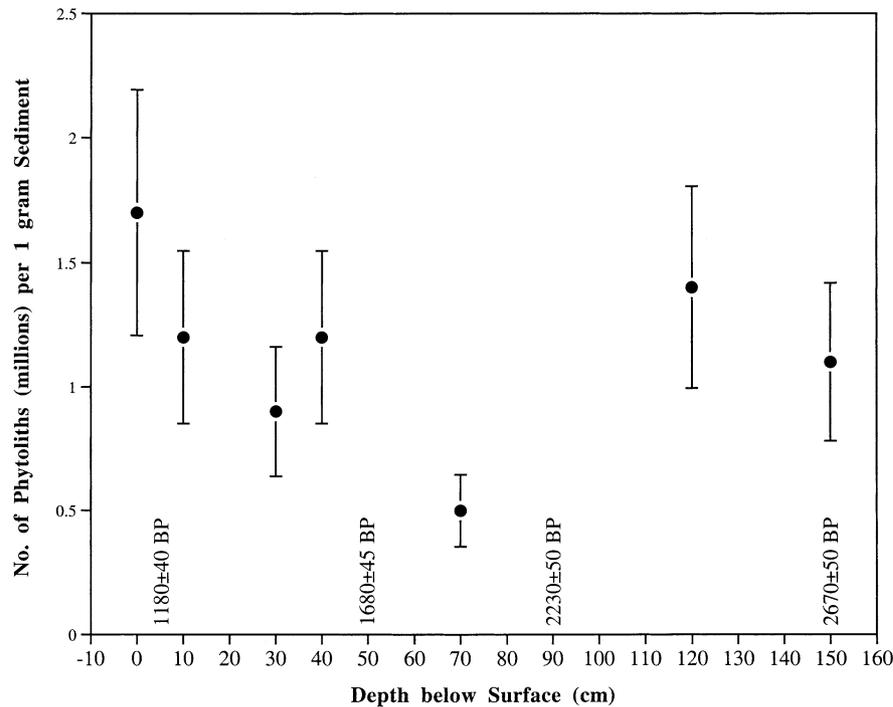


Figure 10. Phytolith concentrations as a function of depth in the deep soil section sampled in order to assess phytolith preservation in soils of the study area. The brackets indicate the counting error of $\pm 29\%$ for each sample. Note the general similarity in phytolith concentrations along the soil profile, indicating that phytoliths do preserve in soils of the study area.

to preserve for very long. It may, however, dissolve and re-precipitate in the form of more stable minerals (see below). There is a rough correlation between the concentration of monohydrocalcite in sediments and the presence of microscopic dung spherulites. This may well indicate that dung spherulites, the exact mineralogical composition of which has not been determined to date (cf. Canti 1997, 1998, 1999), are composed of monohydrocalcite.

We note that organic-rich enclosure sediments from AB20 and also organic-poor enclosure sediments from AB40 contain Mg-rich calcite (Figure 9d). This might be a result of dissolution of monohydrocalcite and re-precipitation of calcite in an environment rich in Mg. Possible sources for Mg are, first, weathering of primary minerals such as diopside, second, weathering of vermiculite, and third, Mg that is found in animal urine (Alfrey, 1985). We also note partial transformation of carbonates to Ca-phosphate. The source of the phosphate is probably degrading organic matter. Formation of Ca-phosphates is the first step along a well-defined diagenetic pathway in which, depending upon the paleochemical environment in the sediment, minerals either dissolve and leave the system, or transform into a more stable form (Karkanis *et al.*, 2000). We can thus expect that ancient caprine enclosure sediments in particular, will contain relatively stable phosphate minerals derived from the primary soluble monohydrocalcite. In contrast, we expect that cattle enclosures will have either none or low quantities of

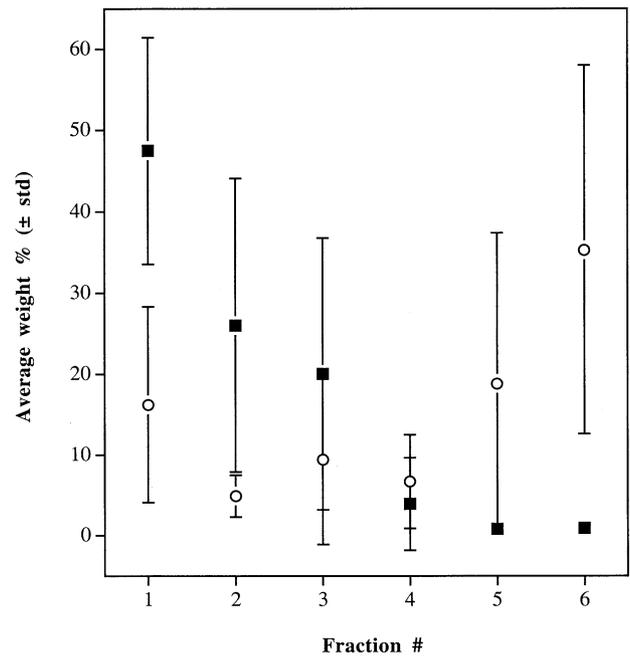


Figure 11. Average weight % of the fractions produced in the heavy liquid separation procedure, of regional sediments (filled squares, $n=10$) and organic-poor enclosure sediments (open circles, $n=11$). Note that light minerals (i.e. opal in fractions 5 and 6) are found in higher amounts in enclosure sediments, indicating higher amounts of phytoliths in enclosure sediments relative to regional sediments.

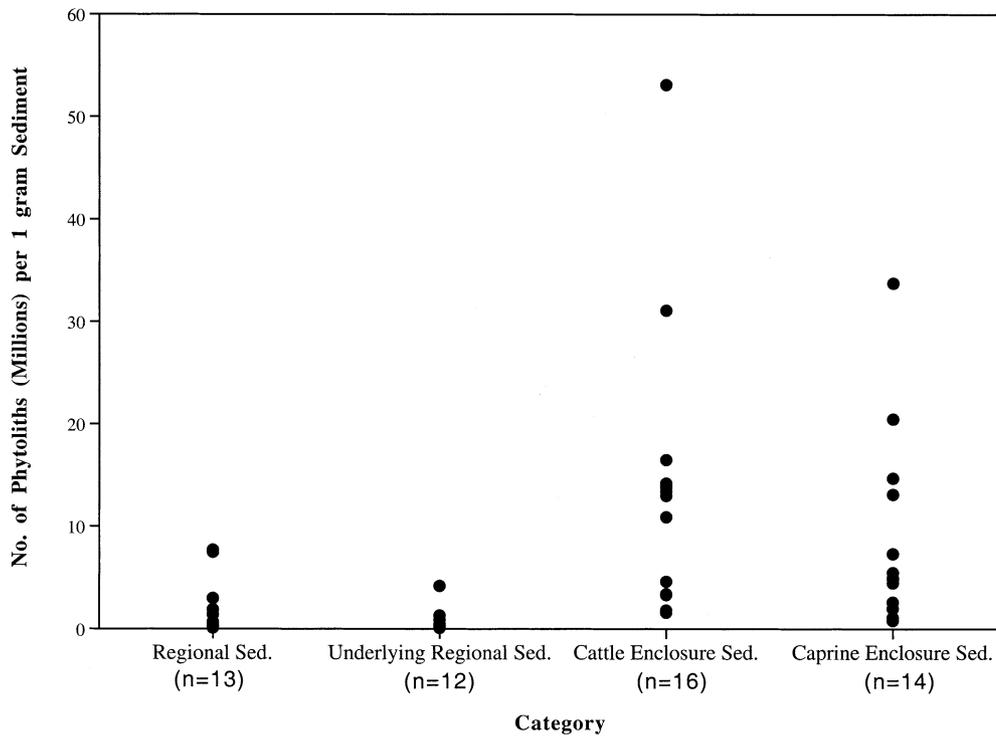


Figure 12. Phytolith concentrations in total sediments from regional and enclosure sediments. Note the restricted and low phytolith concentrations in regional sediments relative to enclosure sediments which have a large range of phytolith concentrations. Refer to text for interpretation.

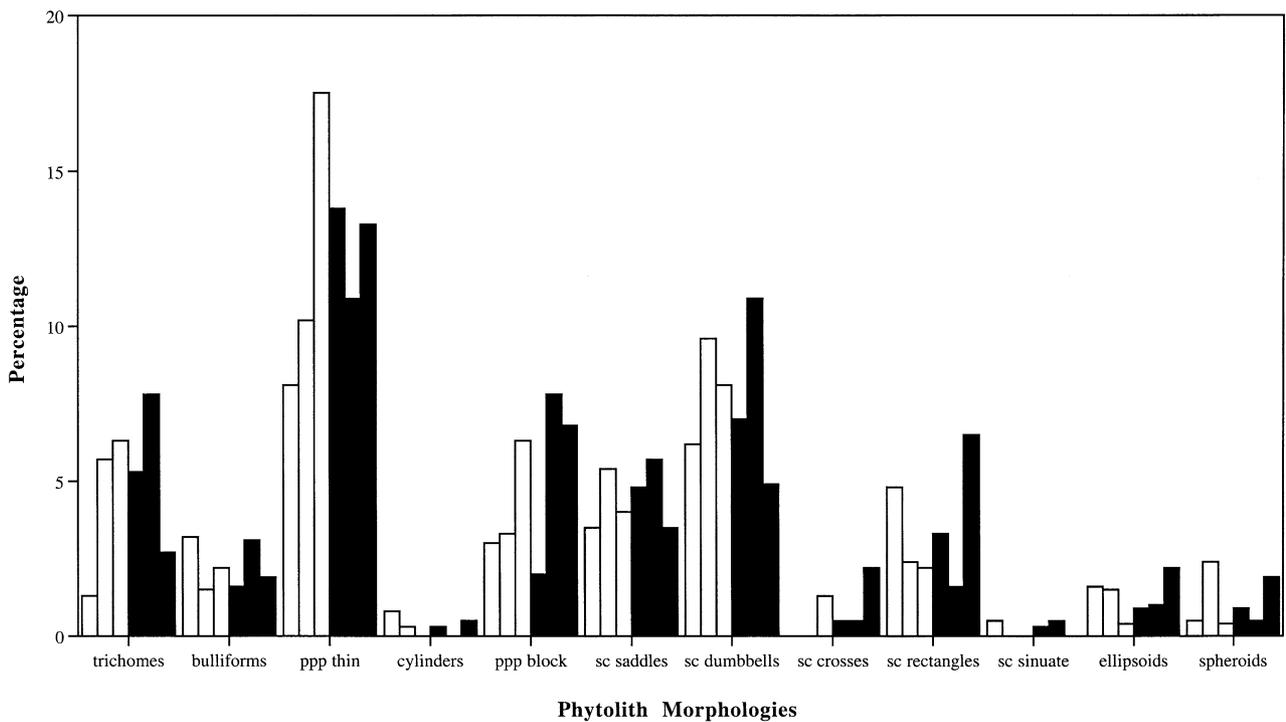


Figure 13. Percentage of phytolith morphological groups in cattle (white) and caprine (black) enclosure sediments. ppp refers to parallelepiped morphology, sc refers to short cells. Note the overall similarity in phytolith morphologies between cattle and caprine enclosure sediments. For detailed description of phytolith types, refer to [Albert & Weiner \(2001\)](#).

phosphate minerals because they are relatively poor in primary monohydrocalcite.

We have further noted that neither monohydrocalcite nor spherulites were found in the caprine enclosures sampled at AB30, and the caprine enclosure sampled in AB20 in the 2001 season. In contrast, enclosure sediments from AB40 are relatively well preserved and do contain monohydrocalcite. AB20 and AB30 are located close to the river while AB40 is located in an elevated area. Enclosure sediments may therefore be better preserved in sites that are located away from water sources.

Dissolved monohydrocalcite is the main source of the carbonate that percolates down the enclosure sediment profile and impregnates the underlying regional sediment. The presence of high amounts of carbonate is the reason why organic-poor enclosure sediments have elevated pH values, and also why the underlying regional sediments have a pH value slightly above that of other regional sediments.

Overall, the mineralogical indicators for enclosure sediments are opal (phytoliths), monohydrocalcite, and its more stable derivatives; Mg-rich calcite and Ca-phosphate minerals.

Phytolith concentration as an indicator of animal enclosures

Phytoliths may preserve for thousands of years in regional sediments of the study area. The phytoliths are pitted, however, in all of the samples analysed in this study, indicating that they have partially dissolved. We also note that organic-rich enclosure sediments contain larger quantities of small opaline fragments than organic-poor enclosure sediments. Furthermore, organic-poor enclosure sediments contain opaline particles that appear to be halves of original dumb-bell-shaped phytoliths. These observations suggest that phytoliths in sediments of the study area undergo dissolution resulting in assemblages that are biased towards large and thick phytoliths. Because opal is relatively soluble above pH 8.5, and because such pH levels occur primarily in organic-rich sediments (probably due to high levels of ammonia from urine), we suggest that this dissolution occurs in the alkaline environment of the organic-rich sediments. Note that high pH values (8.8 ± 0.57) were measured for the water in equilibrium with the organic-rich sediments. Phytolith dissolution greatly diminishes after the pH declines to the regional levels (7.6 ± 0.24), in a matter of 30 years or so after abandonment. This scenario is consistent with the remaining phytoliths surviving for thousands of years in organic-poor sediments.

Phytolith concentrations in most enclosure sediments are higher than in regional sediments (Figures 12 and 4f). Concentrations in regional sediments (including underlying ones) are quite low with the majority of samples (21 out of 25) having less than 2 million

phytoliths in 1 g sediment. Regional sediments with more than 2 million phytoliths in 1 g sediment are primarily from samples taken close to boma gates. These samples may have contained small amounts of dung and hence higher amounts of phytoliths, because of livestock passage through the gate.

The range of phytolith concentrations in enclosure sediments is quite large with the majority of samples (25 out of 30) having concentrations above 2 million phytoliths in 1 g sediment. Samples with low concentrations of phytoliths may result from mistaken identification of the contact between enclosure and underlying regional sediments. We also note that concentrations of phytoliths in enclosure sediments may once have been higher as several taphonomic processes will result in their dilution. These processes may be the addition of clay into the enclosure sediment as a result of clay movement down the sediment profile (i.e. clay elluviation) and/or *in situ* clay formation from weathered primary minerals.

Phytolith counts from other boma features, houses and hearths, show that sediments from these features have concentrations of phytoliths similar to regional, rather than enclosure sediments. Note that in sediments containing abundant soluble minerals, such as monohydrocalcite in caprine enclosure sediments, phytoliths will become more concentrated due to diagenetic loss of the carbonates.

Phytolith morphologies (Figure 13) show that cattle, and sheep and goat, enclosures cannot be distinguished based on the phytoliths present in their dung. Both assemblages are dominated by grass phytoliths. Cattle and sheep are grazers while goats are mostly browsers, but feed on grasses as well. The result of penning sheep and goats together is that caprine dung deposits mostly contain grass phytoliths, similar to those produced by cattle.

In conclusion, concentrations above 2 million phytoliths in 1 g of sediment are indicative of enclosure sediments in the study area. However, because regional and enclosure sediments overlap in the low concentration range, it might be better to only regard significantly higher concentrations of phytoliths, than those in regional sediments, as a definitive indicator of ancient enclosure sediments.

Other indicators

Previous studies noted several other indicators of livestock enclosures. These include shed milk teeth of lambs and kids, goat hairs, insect remains, and diatoms that originate from ingested water (Brochier *et al.*, 1992; Goldberg & Whitbread, 1993). In addition, Watez *et al.* (1990), Courty *et al.* (1991) and di Lernia (1998) report on preserved intact oval caprine pellets. We did not observe these materials and/or structures in open-air sites with organic-poor enclosure sediments.

Implications for the study of site formation processes

This study provides information on early diagenetic processes of organic-rich sediments. Karkanis *et al.* (2000) proposed that diagenesis in prehistoric caves occurs at the surface (i.e. during sediment deposition) or soon after burial. They argue that the driving forces are water passage through the sediment and the presence of large amounts of organic matter (bat guano, in the case of prehistoric caves). Their model also suggests that diagenesis slows down considerably, soon after organic matter is degraded. But, they had very little information about how long organic matter might take to degrade. In this study we show that in open-air sites, almost all the organic matter is degraded within 30 years or so after abandonment. Furthermore, we show that amorphous Ca-phosphate is already forming in a site that had been abandoned for 40 years. If the Karkanis *et al.* (2000) model is correct, then perhaps the changes that take place during the first 40 or so years of site formation encompass most of the major changes that will take place during diagenesis. In this case, we can anticipate that the micromorphological features, mineral distributions and phytolith concentrations observed in this study, could all be potentially preserved in older, archaeological, sites. If this is true, then studying site formation processes using an ethnoarchaeological approach that focuses on sediment sampling in abandoned sites, may be extremely valuable for better understanding the archaeological record.

Practical suggestions

In practice, we suggest that in choosing an archaeological site for excavation, that may have been occupied by pastoralists, the archaeologist should select for settings away from local water sources, because carbonate and phosphate minerals will be better preserved in such locales. Coring the chosen site along a grid may be useful for initial bulk mineralogical analyses in order to locate animal enclosures. It is important to extend the grid beyond the site's perimeter to provide samples of regional sediments that will serve as controls. Once potential enclosures are identified, it is suggested that test pits be excavated and samples for phytolith analyses taken from the surface down the profile every 5 cm. They should cover all strata suspected to be enclosure sediments, as well as the sediments above and below them. Sediment samples may first be analysed using the heavy liquid procedure. The distribution of fraction weight % (as presented in Figure 11) is a useful means of distinguishing enclosure sediments from regional sediments, before actually counting phytoliths. Samples for micromorphology should be taken along open profiles, one above the other with a slight overlap at the boundaries between two samples (cf. fig. 3.9 in Courty *et al.*, 1989). They should include all strata that

are suspected of being enclosure sediments, as well as the sediments above and below them.

Conclusions

Using a combination of micromorphological features, mineral distributions and phytolith concentrations, it is possible to identify livestock enclosures in open-air sites. It is important to note that using one technique alone is not sufficient for a definitive identification of an enclosure and hence pastoralist occupation. In addition, it is important to compare suspected enclosure sediments with regional, control sediments.

This study shows that enclosure sediments differ micromorphologically from regional sediments, because of the unique microlaminated undulating structure that they contain. Mineralogically, enclosure sediments differ from regional sediments by the presence of minerals that are derived from livestock dung, such as monohydrocalcite. Where preservation is poorer, we expect to find the more stable derivatives of monohydrocalcite, namely Mg-rich calcite and/or phosphatic minerals. These are especially apparent in caprine enclosure sediments. Enclosure sediments can also be distinguished from regional sediments by phytolith contents. Concentrations are usually higher than 2 million phytoliths in 1 g sediment, occurring in enclosure sediments. Phytolith morphologies cannot be used to differentiate cattle from caprine enclosures.

This study provides analytical tools with which to identify ancient livestock enclosures in East African sites. These will allow archaeologists to identify pastoral sites more securely and to address questions relating to pastoral expansions in the region. In particular, these methods will allow identification of herding by local hunter-gatherer groups, and discrimination of this practice from accumulation of domestic animals for immediate consumption through trade or raiding. In addition, the same tools will be useful for identifying penning of proto-domestic animals and thus the process of domestication of cattle, sheep and goats in other contexts such as North Africa or the Near East.

This study demonstrates the utility of combining ethnographic fieldwork with quantitative laboratory studies. In addition, a geo-ethnoarchaeological approach enables us to "calibrate" site formation processes, and thus allows control over the timing of diagenesis and a more precise interpretation of site formation processes.

Acknowledgements

R.S.-G. is indebted to K. Ryan and Dr Karega-Munene, without whom fieldwork in Kenya could not have been carried out. We thank Ole Koringo, Lekatoo Ole Parmitoro, S. M. Kahinju, P. M. Kunoni, C. Ngange, K. Seberini and J. Ndungu. Their support

in all aspects of the work, good spirits and personal touch are much appreciated. We thank W. R. Fitts for surveying data, P. Goldberg and P. Karkanas for their comments on the micromorphology, E. Boaretto and E. Mintz for help with the radiocarbon dating of samples, and R. M. Albert for help with phytolith identifications and counting. S. Raz and F. Berna helped with instrumentation and general advice. We are also grateful to three anonymous reviewers for their comments.

Permission for the field study was given to R.S.-G. from the government of Kenya, in collaboration with the National Museums of Kenya. Airphotos and topographic maps were obtained from the Surveys of Kenya with the great help of Z. Otieno, the National Museums of Kenya. This study was supported by an NSF grant (Doctoral Dissertation Improvement Grant, award no. 57508), a Wenner-Gren Foundation grant (Gr. 6663) and the Kimmel Center for Archaeological Science, Weizmann Institute, to R.S.-G., and an Israel Science Foundation grant to S.W.

References

- Akeret, O. & Rentzel, P. (2001). Micromorphology and plant macrofossil analysis of cattle dung from the Neolithic lake shore settlement of Arbon Bleiche 3. *Geoarchaeology* **16**, 687–700.
- Albert, R. M., Lavi, O., Estroff, L., Weiner, S., Tsatskin, A., Ronen, A. & Lev Yadun, S. (1999). Mode of occupation of Tabun Cave, Mt Carmel, Israel during the later Mousterian: a study of the sediments and phytoliths. *Journal of Archaeological Science* **26**, 1249–1260.
- Albert, R. M. & Weiner, S. (2001). Study of phytoliths in prehistoric ash layers using a quantitative approach. In (J. D. Meunier & F. Colin, Eds) *Phytoliths, Applications in Earth Science and Human History*. A. A. Balkema Publishers, pp. 251–266.
- Alfrey, A. C. (1985). Disorders of magnesium metabolism. In (D. W. Seldin & G. Giebisch, Eds) *The Kidney: Physiology and Pathophysiology*. New York: Raven Press, pp. 1281–1295.
- Ambrose, S. H. (1984). The introduction of pastoral adaptations to the highlands of East Africa. In (J. D. Clark & S. A. Brandt, Eds) *From Hunters to Farmers: The Causes and Consequences of Food Production in Africa*. Berkeley: University of California Press, pp. 212–239.
- Ambrose, S. H. (1998). Chronology of the Later Stone Age and food production in East Africa. *Journal of Archaeological Science* **25**, 377–392.
- Ambrose, S. H. (2001). East African Neolithic. In (P. N. Peregrine & M. Ember, Eds) *Encyclopedia of Prehistory, volume 1: Africa*. New York: Kluwer Academic/Plenum Publishers, pp. 97–109.
- Andersen, K. B. (1978). *African Traditional Architecture*. Nairobi: Oxford University Press.
- Banning, E. B. & Kohler-Rollefson, I. (1992). Ethnographic lessons for the pastoral past: camp locations and material remains near Beidha, Southern Jordan. In (O. Bar-Yosef & A. Khazanov, Eds) *Pastoralism in the Levant: Archaeological Materials in Anthropological Perspectives*. Chicago: Prehistory Press. Monographs in World Archaeology No. 10, pp. 181–204.
- Blench, R. M. & Macdonald, K. C. (Eds) (2000). *The Origins and Development of African Livestock: Archaeology, genetics, linguistics and ethnography*. London: UCL Press.
- Boschian, G. & Montagnari-Kokelj, E. (2000). Prehistoric shepherds and caves in the Trieste karst (Northeastern Italy). *Geoarchaeology* **15**, 331–371.
- Bower, J. (1991). The Pastoral Neolithic of East Africa. *Journal of World Prehistory* **5**, 49–82.
- Brochier, J. E. (1983). Combustion et parage des herbivores domestiques. Le point de vue du sédimentologue. *Bulletin de la Société Préhistorique Française* **80**, 143–145.
- Brochier, J. E., Villa, P. & Giacomara, M. (1992). Shepherds and sediments: geo-ethnoarchaeology of pastoral sites. *Journal of Anthropological Archaeology* **11**, 47–102.
- Bull, I. D., Simpson, I. A., van Bergen, P. F. & Evershed, R. P. (1999). Muck 'n' molecules: organic geochemical methods for detecting ancient manuring. *Antiquity* **73**, 86–96.
- Bullock, P., Fedoroff, N., Jongerius, A., Stoops, G. & Tursina, T. (1985). *Handbook for Soil Thin Section Description*. Wolverhampton, England: Waine Research Publications.
- Canti, M. G. (1997). An investigation of microscopic calcareous spherulites from herbivore dung. *Journal of Archaeological Science* **24**, 219–231.
- Canti, M. G. (1998). The micromorphological identification of faecal spherulites from archaeological and modern materials. *Journal of Archaeological Science* **25**, 435–444.
- Canti, M. G. (1999). The production and preservation of faecal spherulites: animals, environment and taphonomy. *Journal of Archaeological Science* **26**, 251–258.
- Courty, M. A., Goldberg, P. & Macphail, R. I. (1989). *Soils and Micromorphology in Archaeology*. Cambridge and New York: Cambridge University Press.
- Courty, M. A., Macphail, R. I. & Watzte, J. (1991). Soil micromorphological indicators of pastoralism; with special reference to Arene Candide, Finale Ligure, Italy. *Rivista di Studi Liguri*, A. LVII, 127–150.
- di Lernia, S. (1998). Cultural control over wild animals during the early Holocene: the case of Barbary sheep in central Sahara. In (S. di Lernia & G. Manzi, Eds) *Before Food Production in North Africa*. A.B.A.C.O. Edizioni, pp. 113–126.
- Dyson-Hudson, R. & Dyson-Hudson, N. (1980). Nomadic pastoralism. *Annual Review in Anthropology* **15**, 15–61.
- Evershed, R. P., Bethell, P. H., Reynolds, P. J. & Walsh, N. J. (1997). 5 β stigmastanol and related 5 β -stanols as biomarkers of manuring: analysis of modern experimental material and assessment of the archaeological potential. *Journal of Archaeological Science* **24**, 485–495.
- Galaty, J. G. (1981). Land and livestock among Kenyan Maasai. *Journal of African Studies* **16**, 68–88.
- Gebauer, A. B. & Price, T. D. (1992). Foragers to farmers: an introduction. In (A. B. Gebauer & T. D. Price, Eds) *Transitions to Agriculture in Prehistory*. Chicago: Prehistory Press. Monographs in World Archaeology No. 4, pp. 1–10.
- Gifford, D. P. (1978). Ethnoarchaeological observations of natural processes affecting cultural materials. In (R. A. Gould, Ed.) *Explanation in Ethnoarchaeology*. Albuquerque: University of New Mexico Press, pp. 77–101.
- Gifford-Gonzalez, D. P. (1998). Gender and early pastoralists in East Africa. In (S. Kent, Ed.) *Gender in African Prehistory*. Walnut Creek: Altamira Press, pp. 115–137.
- Goldberg, P. & Whitbread, I. (1993). Micromorphological study of a Bedouin tent floor. In (P. Goldberg, D. T. Nash & M. D. Petraglia, Eds) *Formation Processes in Archaeological Context*. Madison, Wisconsin: Prehistory Press, pp. 165–188.
- Goren, Y. (1999). On determining use of pastoral cave sites: a critical assessment of spherulites in archaeology. *Journal of The Israel Prehistoric Society* **29**, 123–128.
- Grandin, B. E., De Leeuw, P. N. & Lembuya, P. (1989). Drought, resource distribution, and mobility in two Maasai group ranches, southeastern Kajiado District. In (T. E. Downing, K. W. Gitu & C. M. Kamau, Eds) *Coping with Drought in Kenya*. Boulder and London: Lynne Rienner Publishers, pp. 245–263.
- Harris, D. R. (1996). The origins and spread of agriculture and pastoralism in Eurasia: an overview. In (D. R. Harris, Ed.) *The Origins and Spread of Agriculture and Pastoralism in Eurasia*. Washington, D.C.: Smithsonian Institution Press, pp. 552–573.
- Jones, A. K. G., Hutchinson, A. R. & Nicholson, C. (1988). The worms of Roman horses and other finds of intestinal parasite eggs from unpromising deposits. *Antiquity* **62**, 275–276.

- Karkanias, P., Bar-Yosef, O., Goldberg, P. & Weiner, S. (2000). Diagenesis in prehistoric caves: the use of minerals that form in situ to assess the completeness of the archaeological record. *Journal of Archaeological Science* **27**, 915–929.
- Kruuk, H. (1980). The effects of large carnivores on livestock and animal husbandry in Marsabit District, Kenya. IPAL (Integrated Project in Arid Lands) Technical Report E-4 (ITE Project 675), Unesco Programm on Man and the Biosphere.
- Lamprey, R. & Waller, R. (1990). The Loita-Mara region in historical times: patterns of subsistence, settlement and ecological change. In (P. Robertshaw, Ed.) *Early Pastoralists of South-western Kenya*. Nairobi: Memoirs of the British Institute in Eastern Africa no. 11, British Institute in Eastern Africa, pp. 16–35.
- LeGeros, R. Z. (1991). Calcium Phosphates in Oral Biology and Medicine. In (H. M. Myers, Ed.) *Monographs in Oral Science, vol. 15*. Basel, Switzerland: Karger.
- Lillios, K. T. (1992). Phosphate fractionation of soils at Agroal, Portugal. *American Antiquity* **57**, 495–506.
- Macphail, R. I. & Goldberg, P. (1995). Recent advances in micro-morphological interpretations of soils and sediments from archaeological sites. In (A. J. Barham & R. I. Macphail, Eds) *Archaeological Sediments and Soils: Analysis, Interpretation and Management*. London: University College London, pp. 1–24e.
- Marean, C. (1992). Hunter to herder: large mammal remains from the hunter-gatherer occupation at Enkapune ya Muto rockshelter, central rift, Kenya. *African Archaeological Review* **10**, 65–127.
- Marshall, F. (1990). Origins of specialized pastoral production in East Africa. *American Anthropologist* **92**, 873–894.
- Marshall, F. (2000). The origins of domesticated animals in Eastern Africa. In (K. C. McDonald & R. M. Blench, Eds) *The Origins and Development of African Livestock: Archaeology, genetics, linguistics and ethnography*. London: University College London Press, pp. 191–221.
- Marshall, F. & Hildebrand, E. (2002). Cattle before crops: the beginnings of food production in Africa. *Journal of World Prehistory*, (in press).
- Mbae, N. B. (1986). Aspects of Maasai Ethnoarchaeology: Implications for Archaeological Interpretation. Masters Thesis. University of Nairobi.
- Middleton, W. D. & Price, T. D. (1996). Identification of activity areas by multi element characterization of sediments from modern and archaeological house floors using inductively coupled plasma-atomic emission spectroscopy. *Journal of Archaeological Science* **23**, 673–687.
- Mulholland, S. C. & Rapp, G. Jr (1992). A morphological classification of grass silica bodies. In (G. Rapp, Jr & S. C. Mulholland, Eds) *Phytolith Systematics*. New York: Plenum Press, pp. 65–89.
- Mutundu, K. K. (1999). *Ethnohistoric Archaeology of the Mukogodo in north-central Kenya: Hunter-Gatherer Subsistence and the Transition to Pastoralism in Secondary Settings*. BAR International Series 775.
- Powers, A. H., Padmore, J. & Gilbertson, D. D. (1989). Studies of late prehistoric and modern opal phytoliths from coastal sand dunes and machair in northwest Britain. *Journal of Archaeological Science* **16**, 27–45.
- Price, T. D. & Gebauer, A. B. (1995). New perspectives on the transition to agriculture. In (T. D. Price & A. B. Gebauer, Eds) *Last Hunters, First Farmers*. Santa Fe, New Mexico: School of American Research Press, pp. 3–19.
- Robertshaw, P. T. (1978). The archaeology of an abandoned pastoralist camp-site. *South African Journal of Science* **74**, 29–31.
- Robertshaw, P. & Marshall, F. (1990). Ngamuriak. In (P. Robertshaw, Ed.) *Early Pastoralists of South-western Kenya*. Memoirs of the British Institute in Eastern Africa no. 11, British Institute in Eastern Africa, Nairobi, pp. 54–72.
- Ryan, K., Munene, K., Kahinju, S. M. & Kunoni, P. K. (2000). Ethnographic perspectives on cattle management in semi-arid environments: a case study from Maasailand. In (K. C. McDonald & R. M. Blench, Eds) *The Origins and Development of African Livestock: Archaeology, genetics, linguistics and ethnography*. London: University College London Press, pp. 462–477.
- Sanchez, A., Canabate, M. L. & Lizcano, R. (1996). Phosphorus analysis at archaeological sites: an optimization of the method and interpretation of the results. *Archaeometry* **38**, 151–164.
- Schelvis, J. (1992). The identification of archaeological dung deposits on the basis of remains of predatory mites (Acari; Gamasida). *Journal of Archaeological Science* **19**, 677–682.
- Simpson, I. A., Dockrill, S. J., Bull, I. D. & Evershed, R. P. (1998). Early anthropogenic soil formation at Tofts Ness, Sanday, Orkney. *Journal of Archaeological Science* **25**, 729–746.
- Smith, A. B. (1992). *Pastoralism in Africa: Origins and Development Ecology*. Ohio University Press.
- Thomas, G. W. (1996). Soil pH and soil acidity. In *Methods of Soil Analysis. Part 3. chemical Methods*. Soil Science Society of America, Book Series no. 5, pp. 475–490.
- Touber, L. (1983). Soils and vegetation of the Amboseli-Kibwezi area. In (B. J. A. van der Pouw & V. W. P. van Engelen, Eds) *Reconnaissance Soil Survey Report No. R6*. Nairobi: Kenya Soil Survey.
- van der Veen, M. (1999). *The Exploitation of Plant Resources in Ancient Africa*. New York: Kluwer Academic/Plenum Publishers.
- Wattez, J., Courty, M. A. & Macphail, R. I. (1990). Burnt organo-mineral deposits related to animal and human activities in prehistoric caves. In (L. A. Douglas, Ed.) *Soil Micromorphology: A Basic and Applied Science*. Amsterdam: Elsevier, pp. 431–439.
- Weiner, S., Goldberg, P. & Bar-Yosef, O. (1993). Bone preservation in Kebara Cave, Israel using on-site Fourier Transform Infrared Spectrometry. *Journal of Archaeological Science* **20**, 613–627.
- Western, D. & Dunne, T. (1979). Environmental aspects of settlement site decisions among pastoral Maasai. *Human Ecology* **7**, 75–98.
- Yellen, J. E. (1984). The integration of herding into prehistoric hunting and gathering economics. In (A. Hall, G. Avery, D. M. Avery, M. L. Wilson & J. B. Humphreys, Eds) *Frontiers: Southern African Archaeology Today*. Cambridge Monographs in African Archaeology 10, BAR International Series 207, pp. 53–64.