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Earth, wind, and fire: ethnoarchaeological signals of Hadza fires

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Abstract

We present the preliminary results of an interdisciplinary ethno-geoarchaeological project aimed at characterizing sedimentary aspects of recent combustion structures through soil micromorphology to obtain empirical parameters with which to interpret archaeological features. Micromorphological analyses of five different types of fires made and abandoned by the Hadza of Tanzania were performed and compared with ethnographic descriptions. Their anthropogenic nature, burning intensity and type of fuel used were identified based on the composition and optical features of the microscopic components of the combustion structure. The data provided elements to assess the preservation potential of open air fires and our ability to interpret their function. The life history of two of the fires was reconstructed: a sleeping fire showed evidence of a pre-existing trampled surface, and a communal cooking fire showed evidence of the scooping out of ashes for maintenance. These findings substantiate the important contribution of ethnoarchaeological research conducted jointly with soil micromorphology in discovering cues of human behavior preserved in the sedimentary record.

Keywords: Ethnoarchaeology; Ethno-geoarchaeology; Soil Micromorphology; Fire; Combustion structure; Hadza; Hunter-gatherer

1. Introduction

The goal of this paper is to assess the prospects for tracing the sedimentary components of controlled use of fire in the past. The archaeological manifestation of a combustion structure, often detected from the presence of a delimited zone of reddened or ashy sediment, might include burnt bones, artifacts, artificially arranged stones or concentrated charcoal fragments. For their purely anthropogenic nature, these items enclose behavioral information including technical and functional aspects of the combustion structure, its duration of use and its life history. Some studies on this topic have been concerned with the burnt items found within the combustion structure, analyzing their spatial distribution (Vaquero and Pastó, 2001) or their physical and chemical properties (Stiner et al., 1995). Others have focused on the properties of the burnt sediment, using various geophysical and geochemical techniques (Barbetti, 1986; Bellomo, 1991, 1993; Karkanas et al., 2002; Rudner and Sumegi, 2002; Schiegl et al., 2004).

We apply the technique of soil micromorphology, which entails the study of microscopic components and structures of soils and sediments aimed at the reconstruction of events. The changes caused by fire occurring in the top few centimeters of a burnt soil or sediment are nonreversible. Thus, when this top layer is preserved, micromorphological analysis can potentially answer questions concerning the kind of fuel employed, the function of the combustion structure, the temperature reached, the number of burning episodes represented, the effects on the surrounding sediments, and the degree of post-depositional reworking (Courty et al., 1989). Experimental soil micromorphology has yielded numerous contributions to the characterization of combustion features (Courty et al., 1989; Macphail et al., 2004; Wattez, 1992). This technique has also been previously applied to archaeological combustion

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structures, successfully distinguishing single burning events from multiphased hearths (Meignen et al., 1989; Wattez, 1992), in situ hearths from secondary ash dumps (Schiegl et al., 2003) and domestic hearths from burned stabling layers (Macphail et al., 2004).

Most of the micromorphological case studies analyze Middle or Upper Palaeolithic sites, which have abundant evidence of combustion structures (Meignen et al., 2001, 1989; Schiegl et al., 1996, 2003; Vallverdú, 2001; Wattez, 1992; Weiner et al., 2002). The technique has not been used to investigate earlier sites, such as early Palaeolithic hominin sites in Africa, where the evidence is more scant and the main problem is to distinguish between natural and anthropogenic fires (see James (1989, 1996) for a review of the evidence). Nonetheless, the potential of soil micromorphology in such cases has been demonstrated (Goldberg et al., 2001; Weiner et al., 1998).

We focus on contemporary fires made by the Hadza of Tanzania (for ethnographic background and studies of Hadza behavioral ecology, see Marlowe, 2002, 2003, 2004 and Wood, 2006). Through an ethno-geoarchaeological approach, we developed an experiment coupling sedimentary information obtained from soil micromorphology from different types of Hazda fires with ethnographic descriptions. The Hadza live in open air camps, and the sedimentary signatures of their refuse could provide referential inferences with which to interpret archaeological contexts from similar settings, such as in prehistoric open air sites. The Hadza make fire for many reasons, which we have classified into the following scheme (Table 1): (1) household hearths in camp; (2) sleeping fires inside their huts; (3) temporary communal cooking hearths in camp; (4) tuber roasting fires away from the camp; (5) meat cooking fires away from the camp; (6) special monkey roasting fires; (7) torch making fires to get honey away from the camp; (8) fires to light cigarettes; (9) night and day ambush hunting hearths; (10) fires for straightening arrows and curving bows; (11) burning grass fires.

Ethnographic observations show that ephemeral surface fires may prove difficult to detect after the wind blows the remains around. On the other hand, when the earth is scooped out very deeply and fires burn for a long time, it is easier to detect and recognize as human controlled actions, possibly many years or millennia afterwards. To provide empirical data on this question, we collected and analyzed sediment samples from recently abandoned Hadza fires, which allowed us to investigate and document the effect of these fires on their corresponding sedimentary substrates.

There are few examples of studies using an ethnoarchaeological approach to soil micromorphology with the goal of obtaining reference material on anthropogenic fires (Goldberg and Whitebread, 1993; Wattez, 1992). We analyzed samples from five Hadza combustion structures of different known location, function and duration. Our data allow us to compare the effects of outdoor fires vs. fires in a semi-sheltered space, cooking fires vs. sleeping fires, and very brief vs. prolonged burning events. Such distinctions have not been previously documented in micromorphological terms. The absolute age since abandonment of each of the sampled combustion structures varies: some samples were collected a few days after the burning event and others up to 1 year later. Thus, our data also provide information on the relative effect of taphonomic agents such as wind, rainfall and invading roots over time, offering an insight into the preservation potential of such combustion structures.

2. Methods

Two of us (C.P. and B.W.) collected the micromorphological samples from the following different types of Hadza fires.

(1) *An impala burning fire*. The fire was burning for about 20 min, and was sampled 10 days later.
(2) *An open air cooking fire by a hut*. The fire was burning continuously for 4 months, and was sampled 1 year later.
(3) *A sleeping fire at the entrance of the same hut* (*2 samples*). The fire was burning continuously for 4 months, and was sampled 1 year later.
(4) *A tuber roasting fire*. The fire was burning for about 15 min, and was sampled 1 day later.
(5) *An open air two-family cooking fire*. The fire was burning for 3 months, and was sampled 2 months later.

In each case, sampling involved cutting out small (approximately 7 cm × 4 cm × 4 cm) blocks of sediment from the abandoned combustion structure. This was achieved by gently removing and quickly wrapping the block of sediment in toilet paper and then packing tape. In some occasions, where the substrate was too loose to be removed in one piece, it was necessary to remove the sediments by softly hammering a tin can into the combustion structure.

Where possible, the samples were carefully collected exactly at ground level so as not to miss any fraction of the combustion structure. The substrate of the sampled areas is an acidic, dry, sandy terrain. Details on the morphology and ethnographic observations of each type of fire will accompany the micromorphological descriptions in the Section 3 of this paper, and summaries of all the data are presented in Tables 3 and 4.

The micromorphological samples were processed at the Geoarchaeology Laboratory of P. Goldberg, Boston University, where they were oven dried, hardened with a non-saturated mix of polyester resin and styrene, and cut into 1 cm slabs for thin section preparation. Thin sections of 7 cm × 5 cm and 30 microns in thickness were manufactured by Spectrum Petrographics Inc. They were observed under a polarizing microscope at 40, 100 and 200 magnifications and described following the standard guidelines of Stoops (2003) with reference to Courty et al. (1989) and Wattez (1992), who in a comprehensive analysis of experimental, archaeological and ethnoarchaeological samples, obtained a series of control parameters for the analysis of anthropogenic combustion structures based on the optical characteristics of different sedimentary components at different burning intensities (Table 2).

Table 1
Ethnographic descriptions of the kinds of fire the Hadza make

1	Household hearth in camp	At just about every household, whether a grass hut or just a hacked out bush or rock shelter, there will be a hearth that is used for cooking. This fire is the one kept going at all times by stirring coals. Even when it appears to be out, it is easy to bring it back to flame. Because the average occupation of a camp is about 1–3 months long, this hearth will usually be maintained that long.
2	Sleeping fire inside a hut	A hearth is usually built inside a hut or at the sleeping spot. This is used for warmth while sleeping. The fire is usually kept going on or at least revived every day. When there is no hut the household hearth often serves both purposes: cooking and providing warmth for sleep.
3	Temporary communal cooking hearth in camp	A short-term hearth that could be in the men's place or women's place – under the best shade trees. This fire is communal; occasionally some food is cooked on it when all are sitting and eating together. The fire will also be used to work bows and arrows and coals used to light cigarettes or pipes.
4	Tuber roasting fire away from the camp	When women finish their task of digging tubers, they usually roast up some of them before they take the rest back to camp. They grab some tinder from nearby and have a sizeable bonfire going in a minute or two. This fire is made on top of the ground, not scooped out, and is usually burning with flames about 2 or 3 feet high and gradually allowed to die down as the tubers, which are placed on top of the burning limbs in the middle of the flames are turned over and more added while others are removed. They are roasted for an average of 5–10 min. After pulling them all out, the fire is allowed to die out. Thus, these fires typically last about 10–15 min altogether and are one-time occurrences.
5	Meat cooking fire away from the camp	A bonfire resembling the tuber roasting fire is made away from camp when a man or group of men roasts an animal that has just been killed.
6	Special monkey roasting fire	The same technique as numbers 4 and 5 is used in camp for baboons and vervet monkeys, which are difficult to skin. The animal is placed on top of the flames in order to remove its hair and facilitate pulling the skin off afterwards.
7	Torch making fire to get honey (away from the camp)	When a man or men are out looking for honey and find a promising hive high in a baobab tree full of the stinging bee (*Apis mellifera adansonii*), upon deciding the hive is worth the effort, they will use their fire stick to make a grass fire and then add small twigs. After getting it started, they will cut pegs to use for climbing up the tree. When ready, they find an appropriate piece of wood to set afire and use as a torch. They climb up to the hive and place the torch inside to smoke and stun the bees. After pulling the honeycomb out, they will drop the torch and climb down to eat. They carry some honey off if they have some leftover, leaving the fire smoldering beneath the tree. This fire may burn with flames for about 10–15 min altogether. These fires are made on the ground surface.
8	Fire to light cigarettes	When men are out hunting and want to rest and smoke, they make a fire using their drill. They use dry grass and keep it going long enough to light their cigarette or pipe. Thus, this is probably the most ephemeral fire. It might only be burning for a minute or so, though occasionally they will keep it going and light a second cigarette.
9	Night and day ambush hunting hearth	When men are hunting by waiting in ambush near a waterhole, they make a fire that burns for many hours. This is most often done at night in the late dry season when animals must come to get a drink. The animals prefer to drink after dark in greater safety. Ambush hunting at night is always done in pairs of men rather than a single man. They will get to the water before dusk and build a hearth-like fire, meaning a sizable, circular area with plenty of tinder and eventually a large log or two. The hearth is not scooped out particularly, but often because it must die down to embers and give off no light, they build it behind a mound of earth so that when the animal approaches the water, the mound obscures even the slightest glow. The embers are kept hot by stirring all night to provide warmth for the men who lie besides the hearth waiting and listening for game. The fire smolders for 12 h straight. A variation of this type of fire is made when men conduct an ambush hunt at waterholes in the day. The fire does not have to be hidden as much and so may not be behind a mound, but somewhere not too visible. It is at dawn and dusk that animals are most likely to come, so men must leave camp early enough to arrive at first light and stay until almost dark. This fire is less required for warmth and so it is stirred less often. It is used mainly for lighting cigarettes throughout the day. One variant of multi-purpose fires, both in and out of camp, is when one or more tree limbs, still on the tree and alive but close to the ground, is kept burning slowly for days. This type of fire does not need to be fed with tinder and requires little or no maintenance.
10	Fire to straighten arrows and curve bows	When men are working on arrows or bows or making an ax they will use fire. This is usually in camp but occasionally occurs out of camp. Men will have a fire that looks much like a cooking hearth and, in fact, it is usually the communal fire at the men's place, in which case, it is usually going all day. Men will hold their arrows into the fire and then put them in their mouths to straighten the softened wood. They do the same thing with a new bow, except in this case they are curving the wood and not using their mouth. When making an ax, a man will use the heated up iron blade to burn a hole through the club-shaped wooden handle until he can insert the blade clean through it. Usually this takes an hour or more, so the fire is maintained at high temperature. Often, it will be the household cooking hearth or the communal men's place hearth.
11	Burning grass fire	Men will sometimes start grass fires for a variety of reasons: (a) to eliminate the grass and keep the Datoga pastoralists from coming around with their herds; (b) to get rid of old growth and make way for new growth to attract more game; (c) to clear the ground and make it easier to see game tracks; and (d) to clear the ground so that stepping on snakes is less of a risk.

Table 2
Summary of some analytical parameters for the micromorphological analysis of combustion structures, based on Wattez (1992)

	Low Intensity	Moderate Intensity	High Intensity
Plants	Browned with a reddened core, few elements carbonized	Pseudocarbonized, carbonized elements and ash equally frequent. Ash is brown to yellow	Carbonized, all remains carbonized and partially mineralized. Ash is gray to white. Increased intensity leads to crystalline calcinations (clotting) and fusion
Animal skin	Browned-black, semi-carbonized	Black, total carbonization of fibers	Gray-beige
Coprolites	Orange	Yellow	Gray-beige
Sedimentary substrate	Only organics transform	Fissures in silty–clayey aggregates, minerals start to fragment, organics carbonized. Clays browned with masked birefringence	Granular microstructure, amorphous ferruginous particles turn orange-red, clays pigmented by brown-red speckles, organics carbonized-calcined. Increased intensity leads to microfragmentation and uniform color (red if oxidating; black if reducing) due to the destruction of clays
Combustion structure	TOP-browned-carbonized organics CENTER-slight alteration BASE-no changes	TOP-carbonized organics and yellow-gray ash CENTER-carbonized-calcined organics, fragmented matrix BASE-no changes	TOP-gray-white ash CENTER-strong, deeper effects BASE-same as center

Burning intensity depends on temperature, time of combustion, degree of oxygenation and the nature of the combustible (e.g. dry, wet and dead wood). However, thresholds are mainly dependent on temperature, where <300 °C, low intensity; 350–450 °C, moderate intensity; and >500 °C, high intensity.

3. Results

3.1. The impala burning fire (sample 1)

3.1.1. Field observations: A fire near the kill site of an impala

A 20-year-old man killed an impala on August 27, 2004 and dragged it about 80–100 m uphill from where it died. He came back to camp and at 9:15, six other Hadza, plus two researchers accompanied him to butcher the impala. Several branches were collected from nearby and placed on the ground in sandy, rocky soil on top of a hill. The fire was burning for a short time with flames rising up to 1–1.5 m, but quickly died down. Pieces of meat (rectum, ribs, liver and large intestine) were placed in the fire and cooked for about 20 min (10:30 to 10:50). The hunter continued to butcher the impala with the help of two young boys, and the pieces of meat were moved 9 m to where they were added to the big bonfire. The fire was sampled on September 5, 2004 (9 days later).

On the surface, the burning event left a circular blackened area (60 cm in diameter) with gray ashes in its center (Fig. 1a). The cross-section at the sampled area displayed a horizontal sequence that was deepest and most clear in the middle of the fire, becoming diffuse towards the edges. The sequence comprised a thin layer of gray ashes at the top, followed by 8 cm of black sediments and 8 cm of reddened sediments at the base (Fig. 1b).

3.1.2. Micromorphological observations

Results were obtained from one thin section (7 cm) corresponding with the top half of the combustion structure. The top centimeter comprises a dark gray substrate (dark reddish brown in thin section) of very sandy clays. The groundmass is crumbly, with masked birefringence in the top half. This masked birefringence is due to the presence of abundant charred fine organic material, most prevalent in the top centimeter of the substrate (Fig. 2a). Among the burnt materials there are abundant animal residues, as well as pseudocarbonized wood and

Table 3
Summary of ethnographic data from the Hadza fires

Sample	Description				
	Fuel	Burning environment (reducing/oxidizing)	Burning intensity (as a function of time, temperature and degree of oxygenation)	Function	Age (from time of abandonment to time of sampling)
1	Dry wood-sticks and logs	Open air	Bonfire burning for 20 min, low intensity	Burning of meat (a butchered impala)	10-days-old
2	Dry wood-sticks and logs	Open air	Continuous burning at high temperatures, every day, for 4 months, moderate-high intensity	Family cooking hearth	1-year-old
3, 4	Dry wood-sticks	At the entrance of a hut	Continuous burning at low temperatures, every day, for 4 months, moderate intensity	Family sleeping hearth (for warmth)	1-year-old
5	Dry wood-sticks and small logs	Open air	Bonfire burning for 15 min, low intensity	Brief bonfire for roasting tubers	1-day-old
6	Dry wood-sticks and logs	Open air	Continuous burning at high temperatures, every day, for 2 months, high intensity	Communal cooking hearth	2-months-old

Table 4
Summary of micromorphological observations from the Hadza combustion structures

Sample	Description		
	Organic components	Sedimentary substrate	Taphonomic signature/ postdepositional effects
1	*0–1 cm*: Dense red/orange nodules (100–150 µm); black amorphous impregnations and coatings; pseudocarbonized wood (ash and black tissue), rounded wood ash bundles (300 µm) and angular charcoal fragments	Top half: Crumbly, 40% complex packing voids; 20% sand; 2% gravel. Masked birefringence	None
	2–4 cm: Charred rootlets and angular and rounded charcoal fragments *5–7 cm*: Browned rootlets and scattered angular and rounded charcoal fragments	Bottom half: Crumbly, 40% complex packing voids; 20% moderately sorted sand; 20% gravel. Speckled b-fabrics	
2	*0–1 cm*: Angular and rounded charcoal fragments and punctuations *2–7 cm*: Rounded, scattered charcoal fragments and punctuations	Crumbly, 40% complex packing voids, moderately well-sorted 30% sand with thin clay coatings, 5% gravel. Speckled b-fabrics, weakly granostriated	Frequent channels and fresh rootlets
3	*0–1 cm*: Gray-crystalline wood ash, including carbonized and calcitic cells in anatomical position, angular charcoal fragments, pale yellow/isotropic impregnations and nodules, dense red nodules	*0–1 cm*: Platy, 20% fissures and compound packing voids, 20% sand with thin clay coatings, very few 0.5 mm subrounded soil rip-ups. Calcitic–crystallitic	Artificial compaction and frequent fresh rootlets
	1–2 cm: Charred plant fragments, isolated carbonized cells and roots. Angular and rounded charcoal fragments	*1–2 cm*: Massive, 20% vughs and channels, 40% sand, 5% gravel. Mosaic of dark (masked birefringence) and weakly granostriated patches	
	2–6 cm: Browned and unburnt plant tissue and rootlets, scattered angular and rounded charcoal fragments	*2–6 cm*: Massive, 40% vughs and channels, 40% sand, 5% gravel. Speckled, weakly granostriated b-fabrics	
4	Same as sample 3; *2–4 cm*: Rounded charcoal fragments and fresh rootlets in a sandy lens	*0–1 cm*: Crumbly, 20% vughs and compound packing voids, 20% sand with thin clay coatings, very few soil rip-ups. Calcitic–crystallitic *1–2 cm*: Massive, 20% compound packing voids, vughs and channels, 40% sand, 5% gravel. Mosaic of dark (masked birefringence) and weakly granostriated patches *2–4 cm*: Horizontal lens of packed sand *4–6 cm*: Massive, 20% compound packing voids, vughs and channels, 40% sand, 5% gravel. Speckled, weakly granostriated b-fabrics	Frequent fresh rootlets
5	*0.5–0.8 cm*: Isolated calcitic crystals of wood ash and a few wood ash bundles, abundant browned and black plant tissue and few angular charcoal fragments	*0.5–0.8 cm*: Crumbly, 50% complex and compound packing voids, 20% sand, 5% gravel	None
	1–6 cm: Loose area- isolated calcitic crystals of wood ash and a few wood ash bundles, abundant browned-black plant tissue, few angular and rounded charcoal fragments; Rounded aggregates- scattered rounded charcoal fragments and rare charred tissue	*0–6 cm*: Loose areas – same as above; Rounded aggregates (2–3 cm) – 40% vughs and complex and compound packing voids, 30% sand, weakly speckled matrix with masked birefringence	
6	*0–7 cm*: Grey to white crystalline ash with pseudocarbonized wood tissue, dense pale yellow isotropic grains, and charred animal tissue. At the base (0 cm), carbonized and pseudocarbonized plant tissue, pale crystallitic and black–gray crystallitic ash, pale yellow isotropic grains, dense red nodules and animal tissue	*0–7 cm*: Massive, 10% vughs, fissures and channels, 2% sand. Mosaic gray–white–pale brown calcitic crystallitic, few subrounded reddened soil rip-ups *0–1 cm*: Crumbly, 40% vughs and complex and compound packing voids, 20% sand. Isolated clay-coated grains and reddened speckled clay aggregates	None
	0–8 cm: Browned-black amorphous organic fine material, a charred rootlet at base	*1–8 cm*: Crumbly-granular, 40% vughs and complex and compound packing voids, 30% sand, 20% gravel. Masked birefringence	
	8–12 cm: Scattered rounded charcoal fragments and isolated larger fragments, browned rootlets and pale yellow isotropic grains	*8–12 cm*: Crumbly-granular, 40% vughs and complex and compound packing voids, 30% sand, 20% gravel. Speckled b-fabrics	

charcoal fragments (50 microns in size). Very rare traces of ash were found, present as small (150 microns in size) rounded bundles of calcitic ash crystals scattered throughout the top centimeter of the burnt substrate (Fig. 2b). As one goes down in the profile, there are charred rootlets from 2–4 cm, and below this point they are browned, and the charcoal fragments are generally smaller and more scattered in the groundmass (Fig. 2c). A very small portion of the reddened layer observed in the field

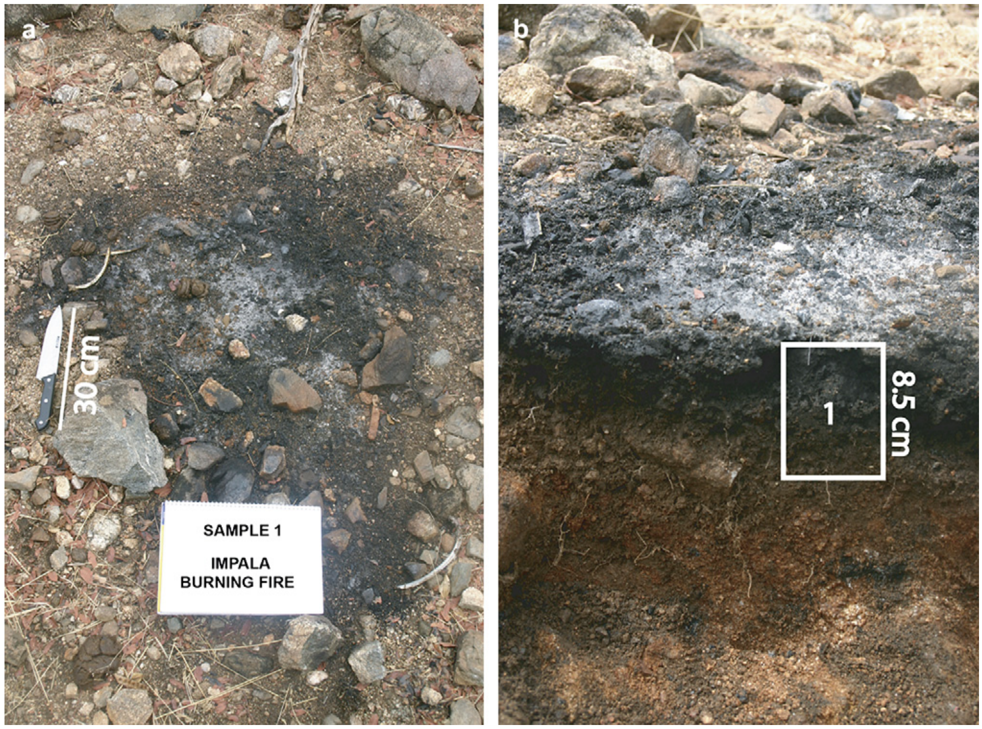

Fig. 1. Impala burning fire. Plan view (a) and cross-section indicating the location of the micromorphology sample (b).

at the base of the fire was captured in the thin section, and it has the appearance of a natural soil (Fig. 2d).

3.2. Open air cooking fire by a hut (sample 2)

3.2.1. Field observations

This was a cooking fire in a camp that had been occupied in the previous years and then abandoned. It was the main cooking fire, about 17 m from the house. It had been occupied from July–October 2003 and was the only fire for cooking everyday during that period. It was excavated 1 year later, on September 5, 2004.

After a year of abandonment, the four boulders that marked the contour of the hearth were found in place and served as landmarks (Fig. 3a, b). They enclosed a small area of about 60 cm in diameter. Only a few shades of gray were left on the crumbly surface, and the cross-section showed a homogenous appearance with abundant fresh roots (Fig. 3c).

3.2.2. Micromorphological observations

Results were obtained from one thin section (7 cm) representing the top portion of the combustion structure, although the contact with the ground surface was lost during sample processing. Throughout its length, the substrate shows a loose, moderately well-sorted dark gray (reddish brown in thin section) sandy clayey deposit with thin iron-rich clay coatings around the grains and common charcoal fragments, speckles and punctuations (25 microns in size). The larger charcoal fragments (125 μm) range from fresh to rounded and are found predominantly at the top of the substrate (Fig. 4a). The base of the sample shows less and more scattered charcoal fragments (Fig. 4b). The groundmass shows properties typical of a natural soil (Fig. 4c). No traces of ash were identified, nor distinctive burnt organic material found, besides the small charcoal speckles, although the clays in the top portion of the sample display a more dusty appearance from the presence of organic punctuations. The substrate appears to have been recently invaded by rootlets – which are fresh and frequent throughout the sample.

3.3. Sleeping fire inside the same hut (samples 3 and 4)

3.3.1. Field observations

This was the sleeping fire inside a hut where a couple had lived from July–October, 2003 (sample 2 was the cooking fire that was used by this couple). This fire was for keeping warm at night and so would have been going almost continuously, or at least revived every night, for about 4 months. It was located at the entrance of the hut.

The fire was sampled 1 year after inactivity. It was found under a light cover of dry grass, partly belonging to the abandoned hut (Fig. 5). In cross-section, its appearance was homogeneous and invaded by roots, similar to sample 2, with a very thin gray layer of ash at the top.

3.3.2. Micromorphological observations

The combustion structure was sampled twice; hence we have two thin sections (3 and 4.7 cm long) representing a single location. Taking together both samples, we observed that the combustion structure is made up of a massive layer of gray ash (light gray in thin section), 1 cm thick, resting on a burnt dark grayish brown substrate (brown/reddish brown in thin section) of sandy clays. The ash is composed of

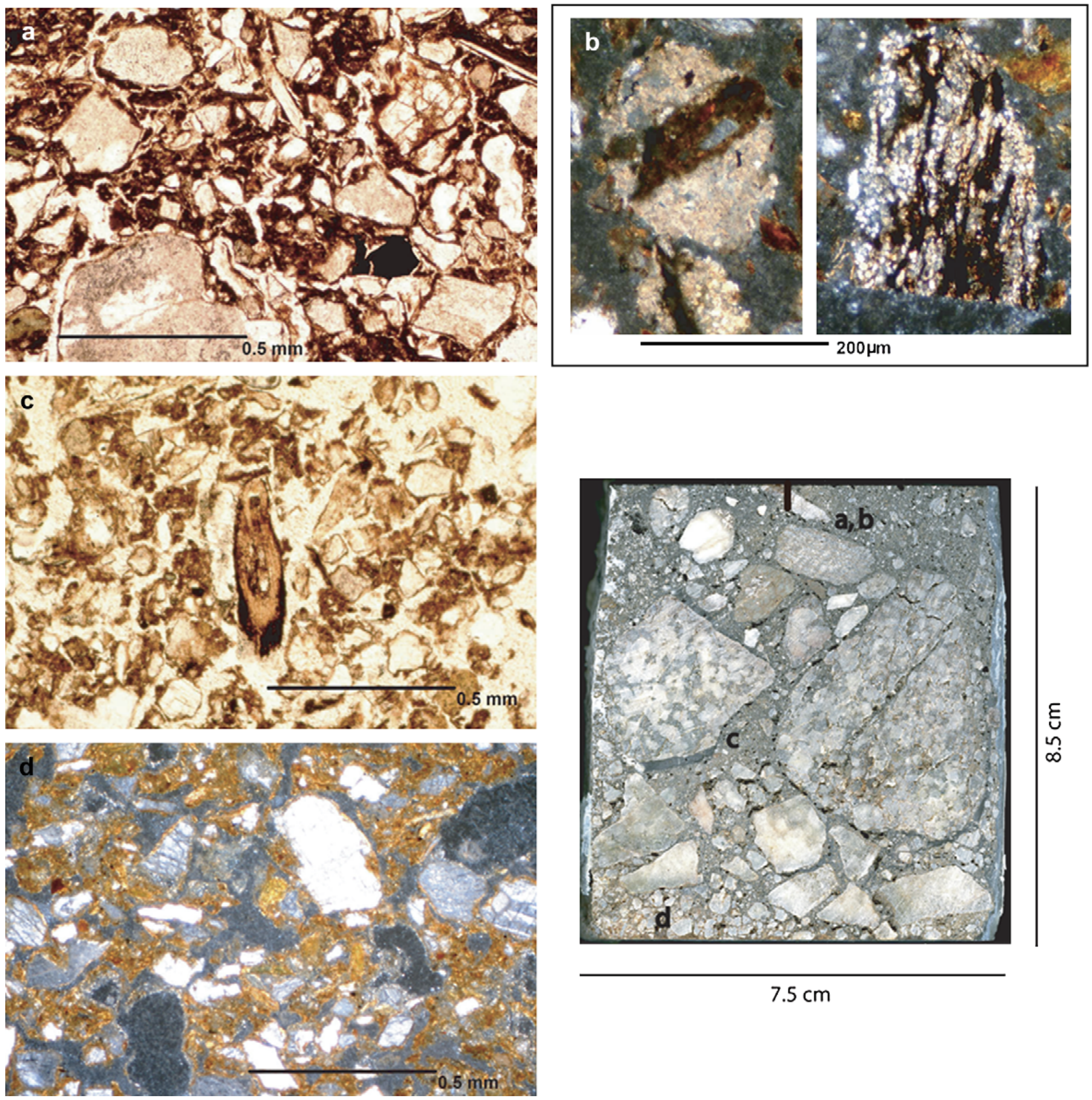

Fig. 2. Impala burning fire. Note that ash (b) is present only as reworked bundles of calcitic crystals or partly calcified wood within the top centimeter of the burnt substrate, which comprises high concentrations of browned organic matter and charcoal fragments (a). The sediments below exhibit very weak traces of burning, mainly scattered charcoal fragments and browned rootlets (c) and the base of the combustion structure – reddened to the naked eye – shows birefringence and microstructure proper of a natural soil (d). 1a and 1c viewed in PPL; b and d viewed in XPL.

calcified wood and leaf cells mixed with charcoal fragments, pseudocarbonized plant tissue, and few dense nodules possibly representing animal residues (Fig. 6a). One phosphatic inclusion was identified as a coprolite. Very few mineral grains, with thin iron-rich clay coatings around them are found floating in the ashy groundmass, as well as rare brown soil aggregates ripped-up from the underlying substrate (Fig. 6b). The top centimeter of the burnt substrate contains abundant browned to carbonized organic particles including plant cells, charcoal speckles and a few whole rootlets (Fig. 6c). The groundmass shows a mosaic birefringence pattern with darker (organic-rich) zones (Fig. 6e) and brighter ones. The porosity in this subsurface portion is composed of large vughs and channels, and these become more abundant with increasing depth. Below 1 cm, the organic fraction, which is the same as above, is only partly burnt or browned, and the charcoal fragments appear both fresh and reworked (rounded) (Fig. 6d). The birefringence fabric of the clayey groundmass below 1 cm is more distinct and homogeneous (Fig. 6f). The state of preservation of this hearth is excellent, as shown by the undisturbed position of the plant cells in the ash. Nevertheless, the presence of fresh rootlets throughout the sample, including through the ash layer, indicates recent bioturbation.

One of the samples from this sleeping fire (sample 3) was slightly compressed in the extraction process and this is reflected in the microstructure of the ash layer, which is platy and fissured horizontally. An overall assessment of samples 3 and 4, taking the artificial compression into account, reveals that the substrate of this combustion structure is made up of compacted sandy clays, more compacted and more sandy than the outdoor cooking fire (sample 2). Towards the top of the burnt substrate, sample 4 displays a thin, well-sorted

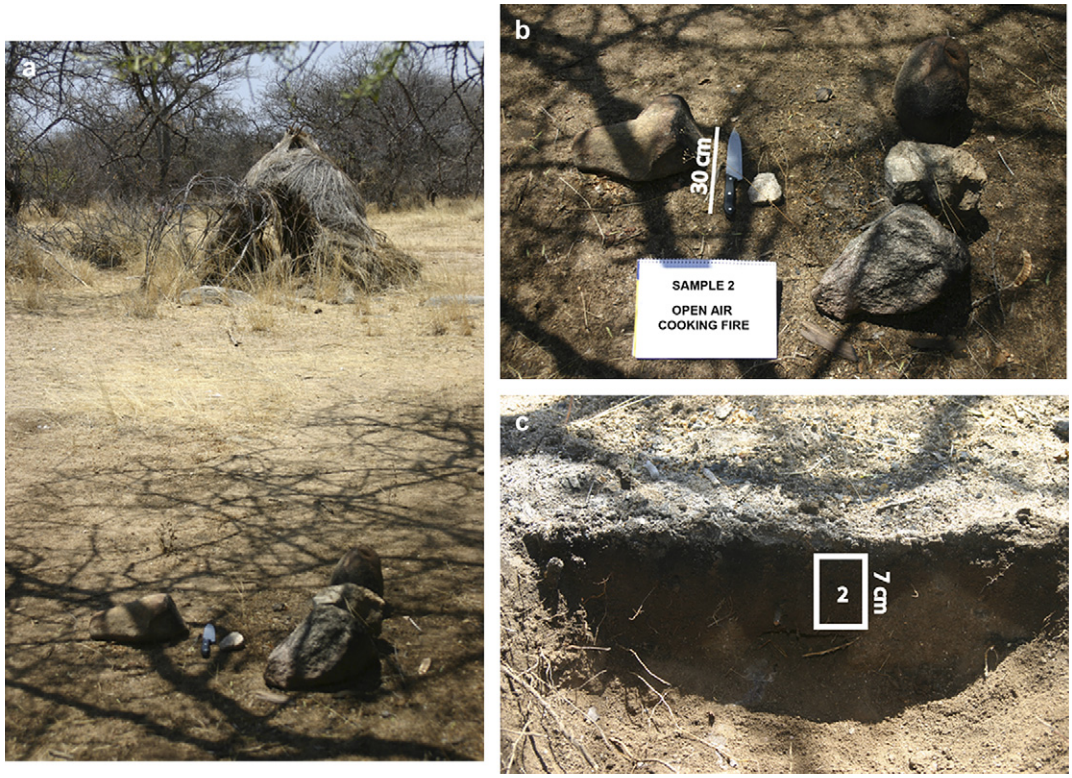

Fig. 3. Open air cooking fire. General context (a), plan view (b) and cross-section with the location of the micromorphological sample (c).

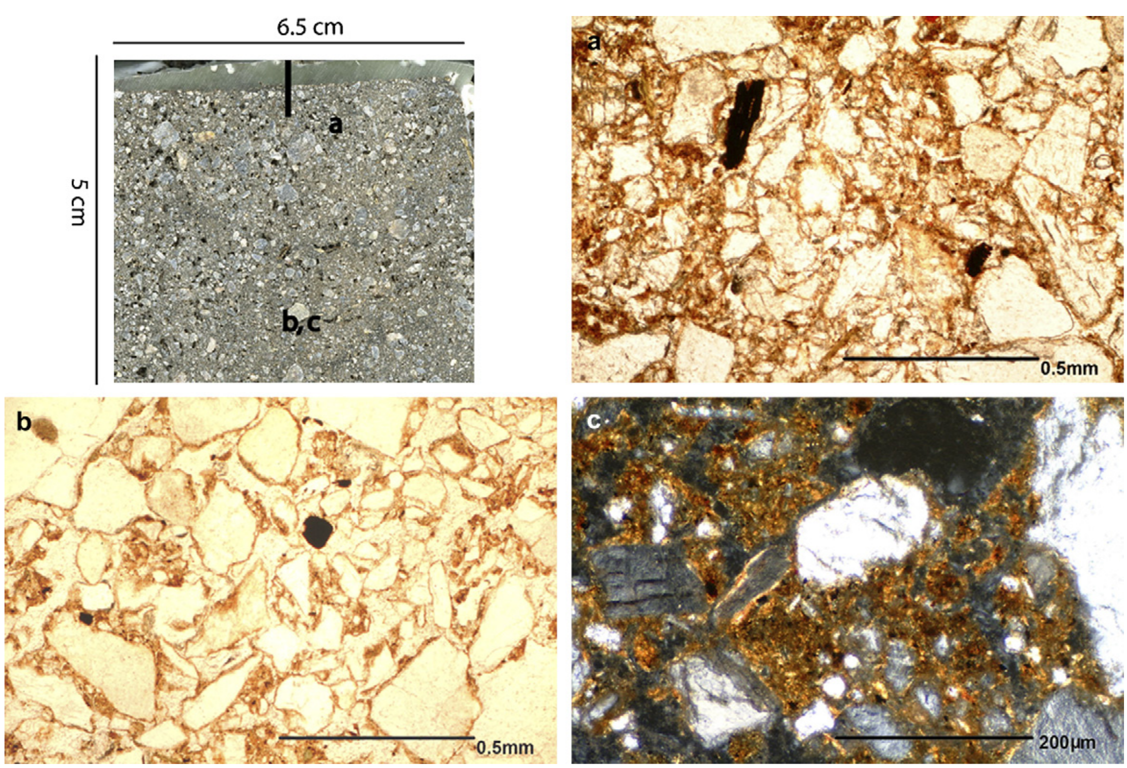

Fig. 4. Open air cooking fire by a hut. The only traces of fire left are reworked fragments of charcoal, scattered throughout the matrix (a, b), which shows a high birefringence in a speckled groundmass (c). a and b viewed in PPL; c in XPL.

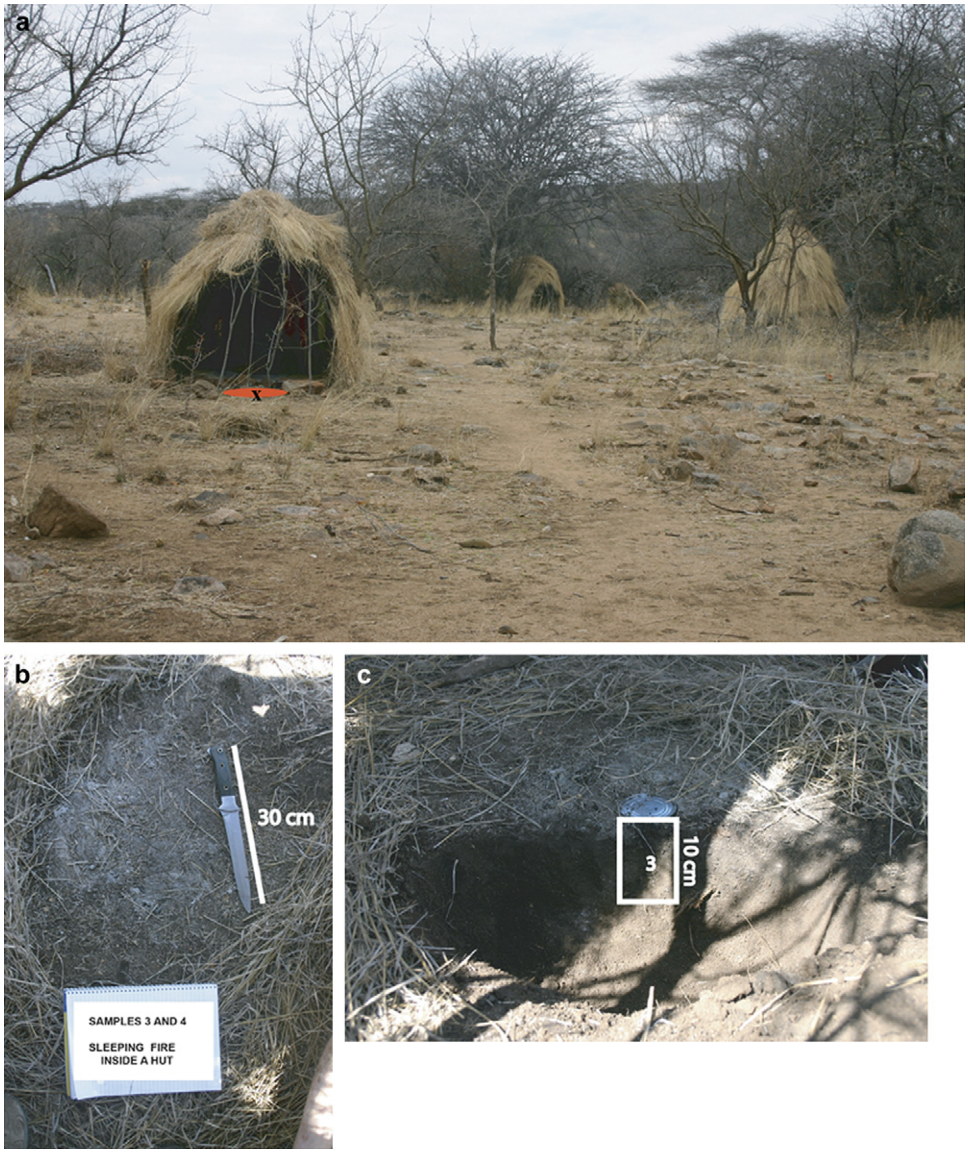

Fig. 5. Sleeping fire inside a hut. General context with red circle indicating the location of the fire (a), plan view (b) and cross-section with location of the micromorphology samples (c).

horizontal lens of fine sand and silt (∼1 mm) with distinct upper and lower boundaries (Fig. 7a and 7b). It has been invaded by fresh rootlets and contains reworked charcoal fragments derived from the combustion structure. Although well-sorted sand lenses of this kind could result from root bioturbation, based on the absence of such features in other bioturbated samples (e.g. samples 2 and 3), as well as from the sharpness of its contact with the underlying soil, we interpret this particular one as residual evidence (recently disturbed by roots) for the existence of a loose sandy ground surface associated with the area of the hut.

3.4. A tuber roasting fire (sample 5)

3.4.1. Field observations

On September 5, 2004 several women and children walked just out of camp and built a bonfire from nearby limbs and then placed their //ekwa tubers on the flames, occasionally turning them over and roasting each for 5–10 min. The flames continued for about 8 min. The sample was taken on September 6, 2004, while the sediments were still moist after a heavy rain.

Similar to the other fires described in this paper, this fire displayed a circular shape of about 60 cm in diameter, and in cross-section, it was composed of a thin layer of light gray ash on the surface, followed by a thin (2 cm) black layer of burnt sediments directly on top of the natural soil (Fig. 8).

3.4.2. Micromorphological observations

Results were obtained from one thin section (7 cm) corresponding to a horizontal cross-section of the combustion structure at the level of the black burnt sediment layer (2 cm down the profile; see Fig. 8c). At this level, the substrate is comprised of aggregated dark gray/grayish brown sandy clays

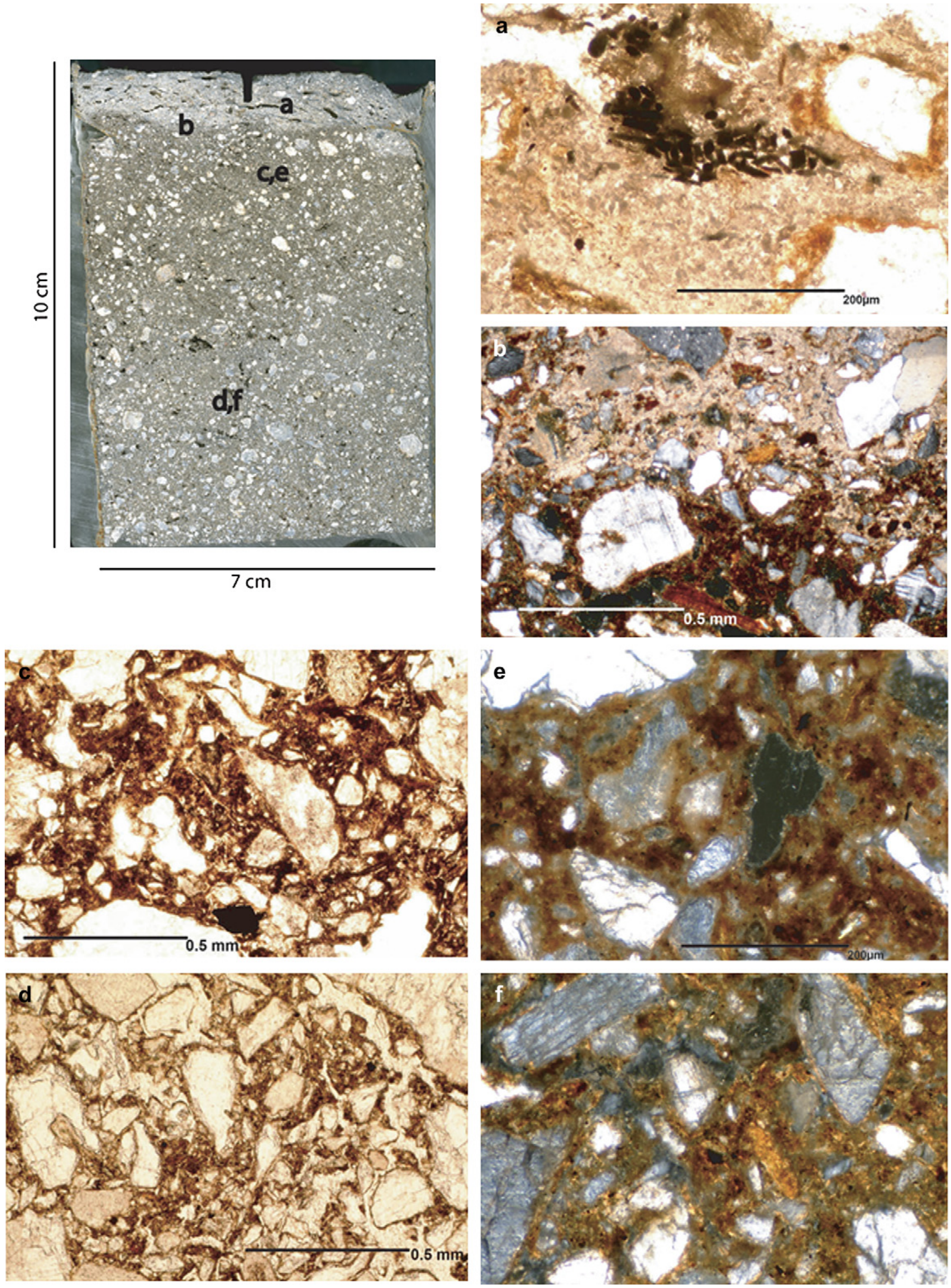

Fig. 6. Sleeping fire inside a hut. Note the presence of a well preserved layer of ash containing calcified and pseudocarbonized wood and isolated grains with oxidized clay coatings (a). The contact with the substrate is sharp, with small rip-ups incorporated in the ash (b) and the top centimeter of sediments contains abundant charred organic material (c) that has masked the original birefringence of the groundmass (e). At the base, the proportion of organics decreases, the charcoal fragments are smaller in size (d), and the birefringence and general appearance of the matrix is that of a natural soil (f). a, c and d viewed in PPL; b, e and f in XPL.

(dark reddish brown/reddish brown in thin section), weakly speckled, and browned by the presence of charcoal and partially carbonized plant tissue and cells. Several rounded and subrounded aggregates of desiccated burnt sediments (Fig. 9a) were identified, surrounded by loose sediments comprising isolated calcitic ash bundles (Fig. 9b) together with well-sorted crumbs of browned and carbonized organic material, and silt-sized mineral grains and crystals of calcitic wood

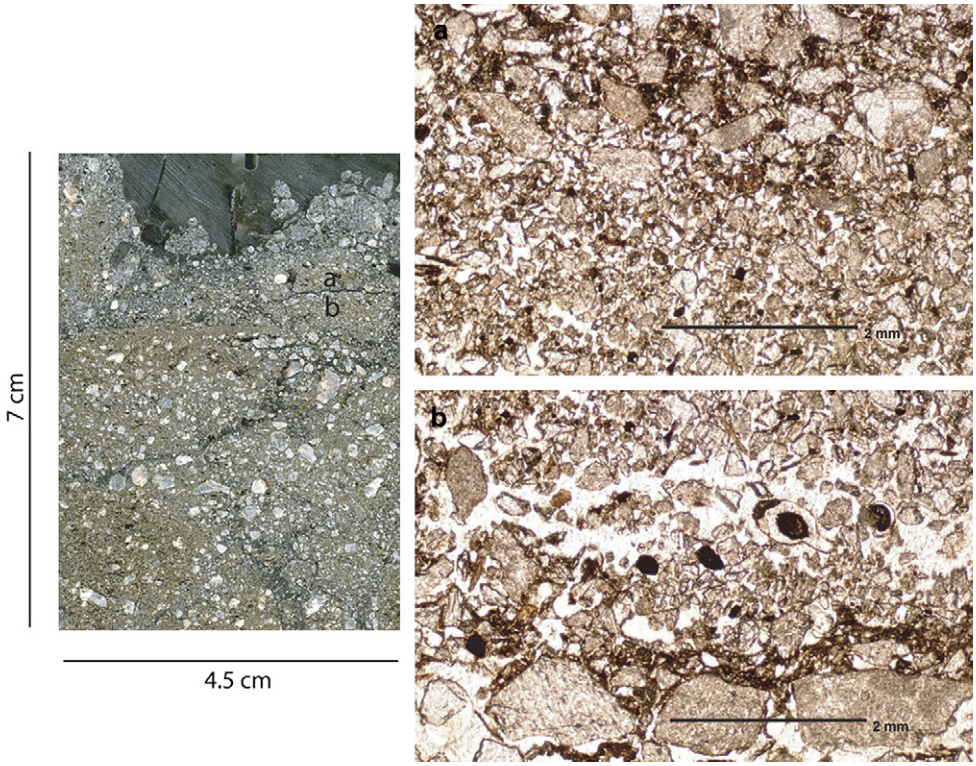

Fig. 7. Buried lens of sand possibly representing a residual former ground surface in the area of the hut prior to the fire. Views in PPL.

ash (Fig. 9c). The rounded aggregates are oxidized, fissured in a way that suggests desiccation, and contain abundant carbonized organic material and calcitic crystals (Fig. 9d). These possibly represent undisturbed and ripped-up parts of the burnt substrate. They show a high birefringence (Fig. 9e), frequent vughs and vesicles, and abundant browned and carbonized organic matter.

3.5. Open air communal cooking fire (samples 6a, 6b and 6c)

3.5.1. Field observations

House cooking fire in a contemporary camp that was occupied at the time of sampling. This hearth was shared by two households and used as a cooking fire. However, they had been using it a few months before the time of excavation on September 6, 2004 even though they were still in the same camp but using a new fire at new houses in slightly different locations. This fire was revived a couple of times every day for cooking. It was periodically maintained by scooping out the top ashy layer, often deep enough to affect the underlying burnt soil. Remains and ashes from the last use of the fire before its abandonment were left in place (note the top layer of ashes in Fig. 10a, containing small bone fragments and other debris). This portion of the hearth was not sampled. The exposed cross-section displayed a light gray ash lens underlain by a concave black layer grading downwards into brown and light brown (Fig. 10c). At the sampled spot, the interface between the ash and the burnt substrate was red (Fig. 10c).

3.5.2. Micromorphological observations

Results were obtained from three consecutive thin sections representing the entire depth of the combustion structure (20 cm). The top 7 cm sampled comprise a weakly fissured, channeled layer of white/light gray ash. In thin section, we can see a mosaic of gray, white, and pale yellow calcitic plant cells and tissue (Fig. 11a). The composition and microstructure of the ash layer is homogeneous from top to bottom, and includes a mix of carbonized and partly carbonized fragments of plant tissue and cells, unidentified phosphatic particles and few possible animal residues. Mineral grains are rare, cracked and etched, as well as a few reddened soil rip-ups and elongated clayey remnants. Some of these clayey intercalations are often found still attached to plant skeletons, suggesting that they belong to the original soil substrate of the burnt plant (Fig. 11b).

At the contact with the substrate, there are isolated, thinly iron-rich clay-coated sand grains and few reworked browned soil aggregates in a very loose microstructure (Fig. 11c, f). Below this and up to 8 cm deep, the burnt substrate is loose, granular, composed of dark gray (reddish brown in thin section), organic-rich sandy clays (Fig. 11d) with a masked birefringence. The organic material is fine, amorphous, and either browned or carbonized. Charred rootlets were identified at around 7 cm beneath the substrate's surface, and vughs, vesicles and channels are common throughout this depth. The bottom portion of the combustion structure (8–12 cm beneath the substrate's surface) is crumbly, with abundant small charcoal fragments and punctuations, very few isolated carbonized plant tissue fragments and common reddened rootlets

Fig. 8. Tuber roasting fire. General view (a), plan view (b) and cross-section (c).

(Fig. 11e). The groundmass in this portion is highly birefringent and speckled (Fig. 11g). The rootlets and the channels that prevail throughout the three samples suggest that bioturbation by roots took place prior to the burning event.

4. Discussion

Using the analytical parameters established by Wattez (1992), we were able to determine the micromorphological signature of anthropogenic fire in all the samples, and the degree of burning intensity in all but sample 2, the 1-year-old open air cooking fire. The use of wood as a fuel was evident micromorphologically. Remnants of burnt wood are found in the ashes (where ashes were present), as well as in the top centimeter of the burnt substrates. In the worst preserved sample (the 1-year-old cooking hearth) the burnt particles do not exhibit any clear morphology, and the only information that could be obtained was that the fuel possibly included wood. Anthracological analysis of the charcoal remains would be able to provide further detailed information including the taxa, the anatomical parts used, and whether the wood was wet, dry or dead. For all of the samples, the absence of phytoliths suggests that grass was minimally used as fuel. From the ethnographic account we know that small amounts of grass

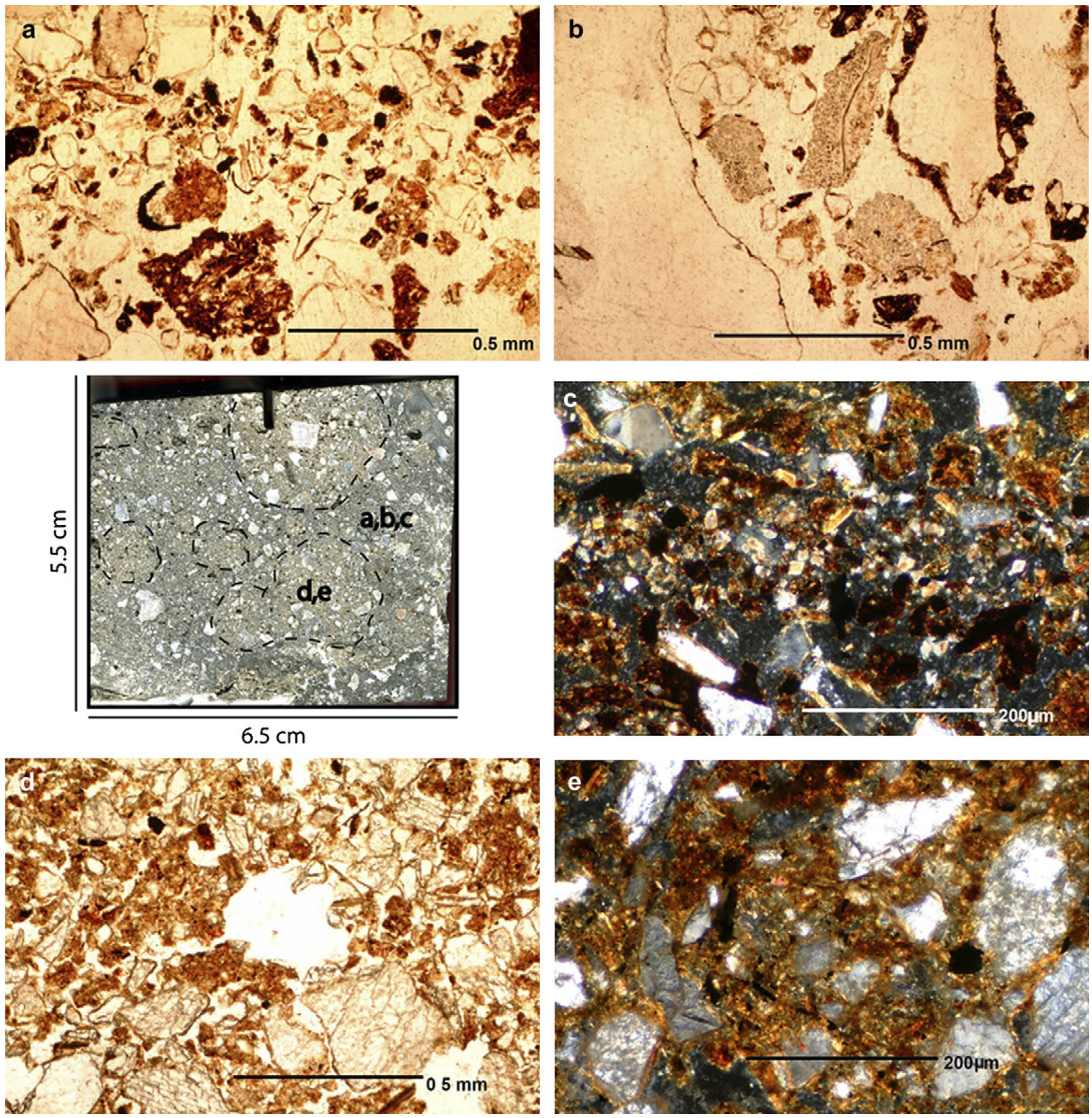

Fig. 9. Tuber roasting fire. The sample captures a planar view of the top centimeters of the combustion structure. Note the loose, crumbly microstructure of the burnt substrate in the area outside of the dashed lines, comprising charred organic material and reworked soil rip-ups (a), rounded bundles of clacitic ash (b) and isolated crystals of calcitic ash mixed with fine organic particles (c). The undisturbed portions of the burnt substrate – encircled by dashed lines – comprise reddened sediments with charcoal fragments (d) and show a high birefringence (e). Views in PPL except c and e (XPL).

were used to start the fire. The use of grass to start fires, together with the light grass cover on the ground and a few scattered dry leaves, would amount to a very low proportion of phytoliths in the ash layer and top centimeter of the samples, which we could identify through phytolith analyses.

These results from a small number of samples provide data for a discussion of the preservation potential of open air and semi-sheltered anthropogenic combustion structures and our ability to reconstruct their function and histories.

4.1. Preservation potential of open air and semi-sheltered combustion structures

In sample 1, we had the opportunity to observe the sedimentary effects of an ephemeral surface burning event. Although the ash layer disappeared after only 10 days in the open air, burning directly on the ground for 20 min had nonreversible effects on the substrate which, given rapid sedimentation and geochemical stability, could be preserved over time. The main marker features are: a reddened (oxidized) clayey groundmass, microstructural disaggregation enhanced by burning of the organic fraction, the presence of charred organic matter including plant and animal residues, and isolated, reworked bundles of calcitic ash. Following Wattez's parameters, these are the features indicative of a burning event of moderate intensity. However, the observations from sample 2 may serve to address the influence of taphonomic effects. After 1 year of abandonment in a relatively acidic substrate in the open air, with no sedimentary accretion and under the effects of bioturbation by roots, the remnants of a cooking hearth that burnt continuously for 4 months were limited to an oxidized clayey groundmass with isolated charcoal speckles. No traces

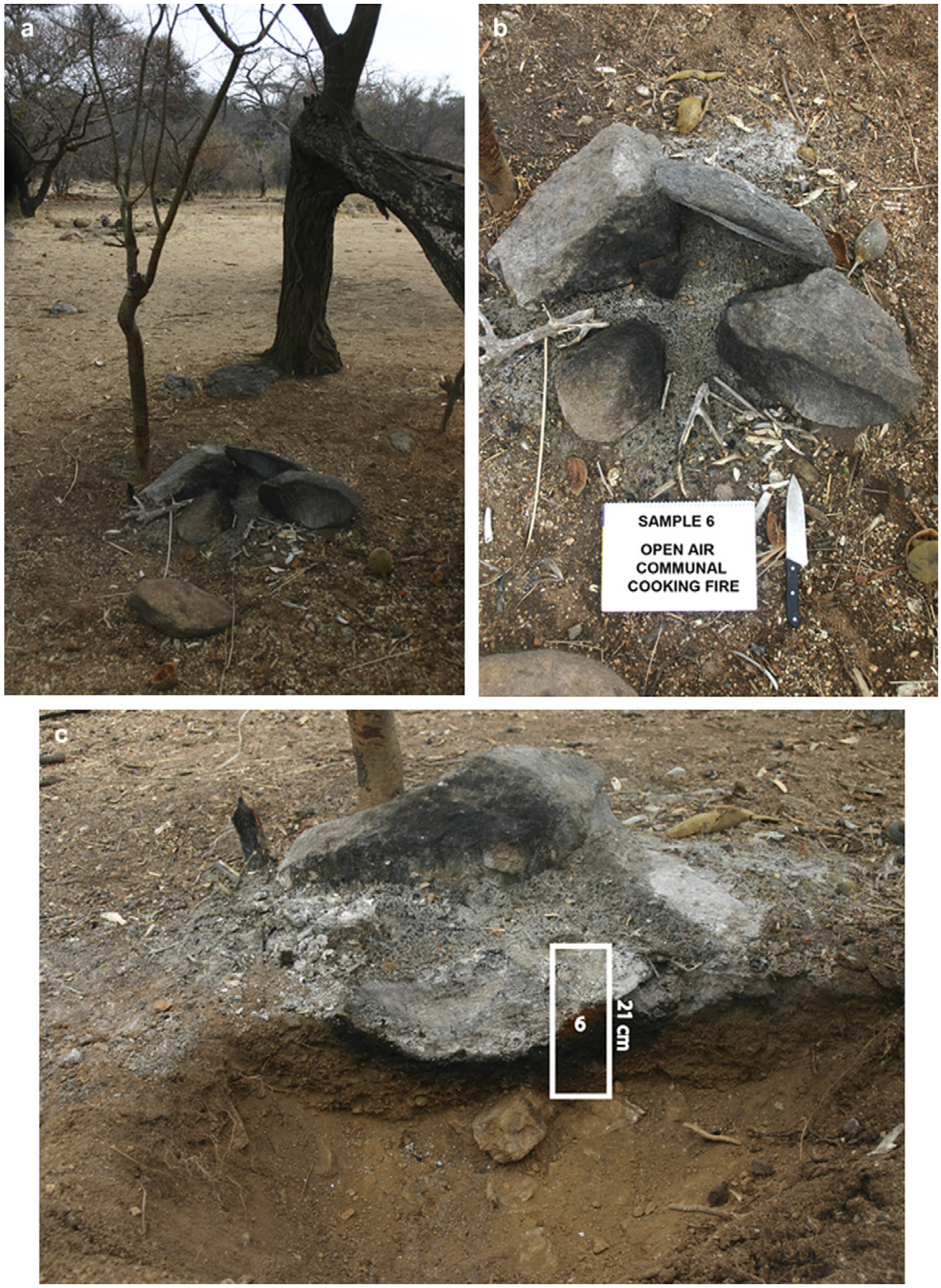

Fig. 10. Open air communal cooking fire. General context (a), plan view (b) and cross-section with the location of the micromorphological sample (c).

of reworked ash or of burnt organic tissue were left in the preserved substrate. In this case, the effects of taphonomic agents destroyed the original combustion structure and the only remaining traces of the burning event were few carbonized organics in a reddened substrate.

Contrary to this situation, the sleeping hearth (samples 3 and 4) shows very good states of preservation and indications of a burning event of moderate intensity: 1 cm of gray ash is present, as well as 1 cm of organic-rich burnt substrate and an underlying reddened groundmass speckled by charcoal. The thin layer of dry grass (from the collapsing hut) that covered the abandoned fire protected it from the erosional impact of wind and rainfall of that year. The sleeping fire documented a similar degree of root bioturbation to that observed in the outdoor cooking fire (sample 2), yet its original microstratigraphic structure was preserved. This suggests that erosion played a stronger role than invasion by roots in the preservation of both of these combustion structures.

Sample 6 represents an outdoor hearth that had been used 2 months prior to excavation. It yielded 7 cm of light gray ash and a 12 cm deep burnt substrate. Similar to samples 3 and 4, its good preservation allowed us to detect certain microstratigraphic features related to the function and history of this cooking fire. After 2 months, root bioturbation had not yet

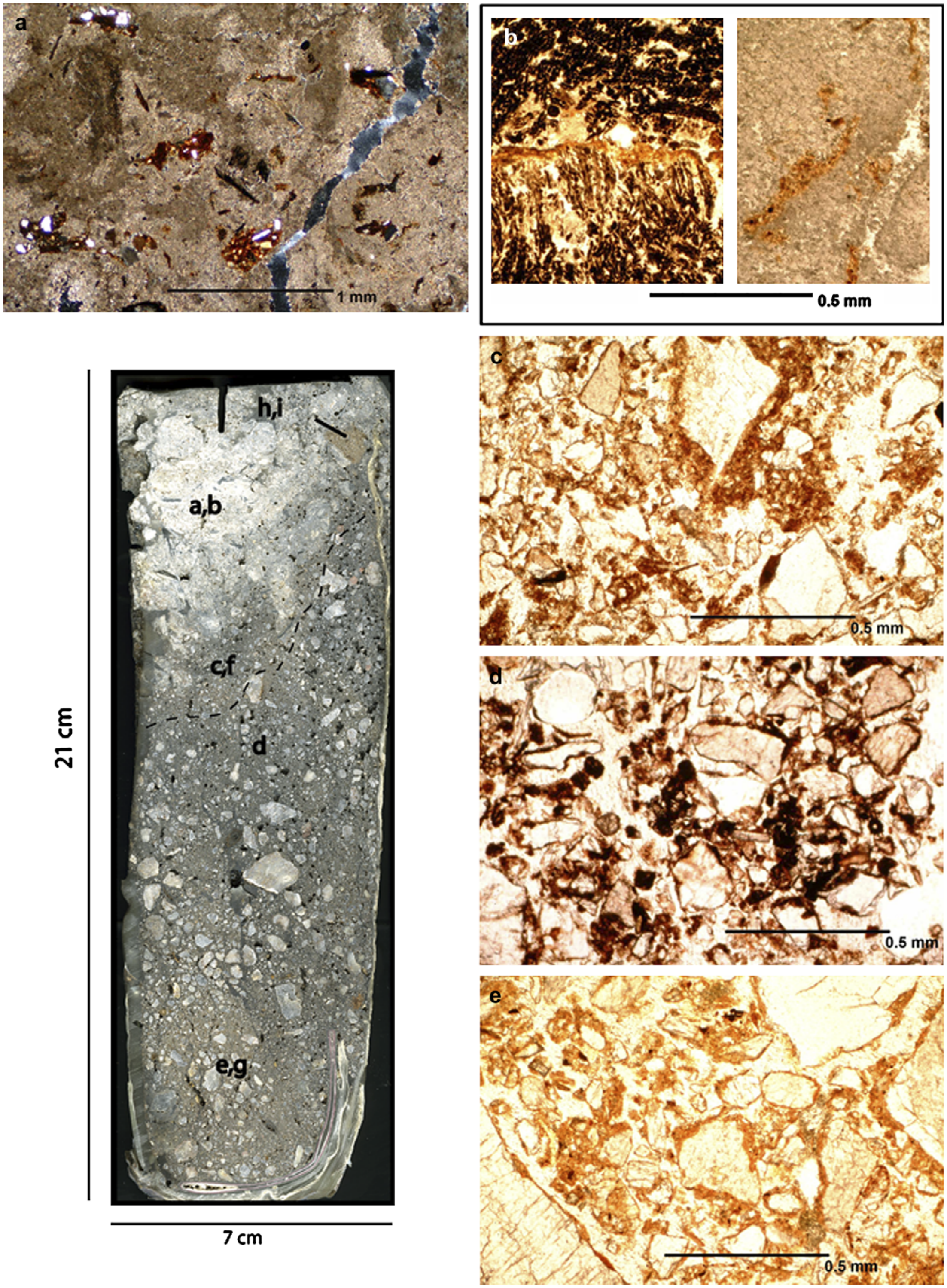

Fig. 11. Open air communal cooking fire. The ashes made up of a gray-light gray mosaic of calcitic wood cells and pseudocarbonized fragments, as well as burnt sediment rip-ups (a, detail in h, i) and residual clay intercalations (b). The top centimeter of the burnt substrate comprises reddened clays lacking charred organics (c, f), underlain by burnt sediment with a high concentration of organics (d). The sediments at the base of the combustion structure have the appearance of a natural soil (e, g). b, c, d and e viewed in PPL; a, f, g, h and i in XPL.

occurred. Sufficient diagnostic features were preserved to classify the sample as an anthropogenic combustion structure of high intensity. The distinction between moderate (e.g. the sleeping hearth) and high (this fire) was mainly observed in the degree of carbonization and calcination of the ash components, the coloration of the ash layer, and the microstructure of the underlying burnt substrate, which was weakly aggregated in the sleeping hearth and granular in sample 5.

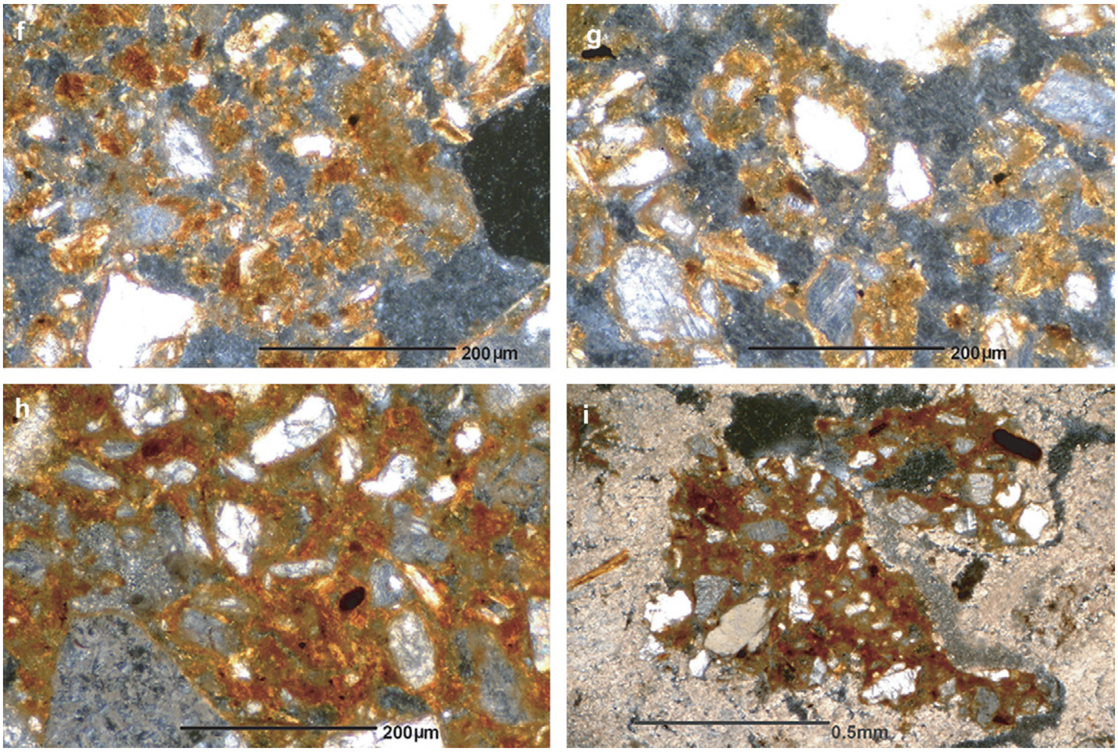

Fig. 11 (*continued*)

Micromorphological results suggest that the anthropogenic signature of open air combustion structures can be detected depending on the rates of sedimentation and the impact of postdepositional disturbance factors such as root invasion. If the rates of sedimentation are low, leading to erosion, the remains of an ephemeral open air fire are likely to disappear. Long-duration fires might be identifiable as anthropogenic fires, but not interpreted any further. In cases where the rates of sedimentation are high or the combustion structure is buried and hence protected from erosion, even if root invasion has played a role, open air fires can be successfully interpreted through soil micromorphology.

4.2. Function

If the features observed micromorphologically had been found in an archaeological context, would it have been possible to reconstruct the function and history of any of these fires? From ethnographic accounts we know that there are clear functional distinctions among the fires sampled, but soil micromorphology yielded little information on this regard. The sample of the impala burning fire yielded few, scattered animal residues – possibly grease, hemoglobin and organic fluids– and their preservation potential is questionable. They were found in the very top of the burnt substrate, mixed in with the charred organics, and could easily go undetected in an archaeological context. Nevertheless, we must note that the anthropogenic incorporation of organics into the top of the substrate, such as in the cases of the impala and tuber roasting fire, yielded higher amounts of microscopic organic matter in comparison with the other samples. We might consider this factor (the presence of high amounts of organic matter) in the comparative study of synchronous combustion structures in archeological sites where the potential for the preservation of burnt organic matter is high, such as Abric Romaní, Spain (Pastó et al., 2000) and Kebara, Israel (Meignen et al., 1989).

From ethnographic observations we know that Hadza cooking fires were commonly used to roast and boil meat, roast tubers, boil berries, and when they happen to get some maize through trade, boil maize porridge. We analyzed two different cooking hearths (samples 2 and 6) and neither provided elements diagnostic of the activity of cooking except for isolated particles possibly representing burnt seeds and animal residues. The ashes contained abundant burnt plant fuel remains. Anthracological and phytolith analyses could possibly distinguish plant species, particularly in a case such as the tuber roasting fire, where the charred tissue is incorporated into the top of the combustion structure leaving abundant cm- and mm-sized remains. The clearest proof that function is difficult to determine is the similarity in composition between the cooking and sleeping fires. The differences in the nature and amount of charred organic particles within the black layer of both types of hearths were not diagnostic. The pre-existence of a trampled surface in the sleeping fire is not directly representative of a particular function, although it can be considered as indicative of a habitation site. The only micromorphological difference between samples 3, 4 (sleeping fire) and 6 (cooking fire) that could be diagnostic of function is the degree of burning intensity of the combustion structure.

Sample 6, the cooking fire left a stronger impact in 2 months than the sleeping fire in four. Its ashes were white and the burning effects on the substrate, deeper, all indicative of a higher intensity in comparison to the gray, shallow structure of samples 3 and 4. This evidence corresponds to the ethnographic observation that sleeping fires are kept burning at low intensities in order to avoid fire hazards in the vicinity of the hut. Further confirmation of this point could be provided by anthracological analysis of the charcoal fraction, which would be able to distinguish between fragments of large wooden logs (used for high intensity cooking fires) vs. small twigs and sticks (used in sleeping hearths).

The function of combustion structures is difficult to determine based on soil micromorphology. The technique yielded only two parameters that may serve as possible indicators of function: (1) the amount of organic matter, which if high may be associated with roasting; and (2) the burning intensity, which has shown to be high in cooking fires and low in sleeping fires. There are other types of fire that the Hadza make that we did not sample, such as surface grass fires to light torches, ephemeral cigarette lighting fires, hunting bonfires, wooden artifact tending fires, and extensive grass fires. Based on our preliminary results, the anthropogenic signature in these types will also be weak and indistinct from one to the other, although the grass fires could be characterized from their lack of wood ash and from the presence of phytoliths.

4.3. Fire histories

Our preliminary study has contributed two findings in this regard. The first comprises features indicative of a compact surface on which people possibly slept prior to the time of building the sleeping fire (samples 3 and 4). This observation is relevant for evaluating the different impact of Hadza activities on the sediments throughout the camp, and might suggest that the area surrounding the hut was more intensively used than the areas where the other fires were made. However, we derive this preliminary interpretation from a single finding, and systematic sampling of ethnographically documented areas is necessary to clarify this issue.

The second finding, in sample 6, shows indications of the scooping out of ashes for the maintenance of a cooking fire. To the naked eye, the concave outline of the contact between the ash layer and the underlying blackened sediment suggests that the fire was built on a slightly hollowed out substrate. The microstratigraphy of sample 6 includes a layer of ash underlain by approximately 1 cm of crumbly reddened sediment lacking a significant amount of organics. Instead, the density of burnt organics is apparent only approximately 2 cm down the substrate. This suggests that the reddened sediment directly beneath the ashes does not belong to the same substrate. Moreover, reworked reddened soil clasts were found within the ashes, possibly ripped out of the substrate during the scooping activity.

The two cases illustrate the high potential of soil micromorphology to reconstruct the history of combustion structures. In the future, micromorphological analysis should focus on Hadza fires that have served different functions in order to approach this problematic factor in more depth.

5. Conclusions

This study attempted to document sedimentary signatures of human-made fires that could be applied to the archaeological record. It represents the first steps of an ethno-geoarchaeological investigation aimed at obtaining independent evidence to test micromorphological interpretations. Such an approach comes in a time when there is increasing archaeological interest in pyrotechnology and when prehistoric excavations can provide high resolution multidisciplinary data on combustion structures. Thanks to the benefit of a feedback between the ethnographic context and its microscopic representation, it was possible to assess what questions we can answer faced to the sedimentary remains of an anthropogenic fire.

It was shown that soil micromorphology has the potential to: (1) distinguish between natural and anthropogenic fire, (2) to estimate the burning intensity of combustion structures and in some instances, and (3) to identify the type of fuel used. In addition, this study provided insight into three main aspects of combustion structures relevant to archaeology: their preservation potential, the interpretation of their function, and the reconstruction of their use histories. For any given prehistoric site, coupling this kind of information on fire features with associated archaeological evidence can highly contribute to our understanding of other aspects of collective behavior such as spatial organization, site use and site duration.

This preliminary study needs to be complemented by a larger collection of samples, including samples of Hadza grass fires, natural fires documented in Hadzaland in the recent past and unburnt control samples. Anthracological and phytolith analyses should be incorporated into the study, as they provide important data to support micromorphological observations.

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