Ethnoarchaeology of Paleolithic Fire: Methodological Considerations

Carolina Mallol, Auréade Henry

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Most of the ethnoarchaeological literature on hearths is scattered within general works that target many different aspects of foraging or hunter-gatherer societies. Although these works are a good source of ideas and clues for the interpretation of macroscopically observable features of Paleolithic hearths, there is hardly any high-resolution ethnoarchaeological reference material with which to compare microstratigraphic evidence of archaeological fire. Our ethnoarchaeological research at this scale has focused on exploring differential preservation of open-air hearths and the potential to identify fire-related activities and different variables of fire technology (fuel, temperature, and function) using micromorphological and anthracological analysis. Although these studies have been useful sources of analogy, further case studies as well as ethnoarchaeological examples of superposed and imbricated hearths and reference material from enclosed settings such as caves and rock shelters are strongly called for. In this paper we summarize and discuss aspects of our previous work to highlight the strengths and weaknesses of the ethnoarchaeological approach for the study of Paleolithic fire and propose possible avenues for future research on the topic.

Fire has played a fundamental role in the biological and social evolution of humankind. Omnipresent in the domestic and ritual spheres since Paleolithic times, it has been influential for our diet and associated with the emergence of technological, sociological, and artistic expressions in different past societies (Perlès 1977). However, despite its potential to furnish valuable behavioral information on our most distant past, anthropogenic fire has been an elusive topic in prehistoric research. Most researchers have focused on trying to establish the presence or absence of fire in Paleolithic contexts in order to ascertain the timing of fire control and use, rarely examining the evidence in order to better understand human lifeways.

Nevertheless, there is a growing number of studies on archaeological combustion structures, combustion residues, and other elements of the archaeological record bearing traces of burning. Such archaeological remains convey not only socioeconomic, dietary, and paleoenvironmental information but also clues to site formation and taphonomy. All of these aspects are central to Paleolithic research. Accordingly, recent methodological approaches from different archaeological subdisciplines (particularly geoarchaeology, archaeobotany, and zooarchaeology) have contributed valuable data to advance our knowledge of Paleolithic fire and fire-related activities (Aldeias 2017; Alperson-Afil 2017; Costamagno et al. 2009; Hlubik et al. 2017; Holdaway, Davies, and Fanning 2017; Mentzer 2014; Théry-Parisot, Chabal, and Costamagno 2010).

Among these approaches, bioarchaeological analyses (in the sense of analysis of organic materials) of combustion remains—commonly charcoal, but also bone or phytoliths—provide valuable taphonomic data in relation to fuel management and hearth functionality, thus allowing us to better understand environmental and economic aspects of past societies (Théry-Parisot, Costamagno, and Henry 2009). Similarly, geoarchaeological analyses of hearths or combustion structures, which are in fact sedimentary artifacts, contribute similar kinds of information in addition to an understanding of the hearths' formation processes (Goldberg, Miller, and Mentzer 2017; Mallol, Mentzer, and Miller, forthcoming; Mentzer 2014).

With increasing studies of anthropogenic fire in Paleolithic archaeology, it has become relevant to incorporate this topic into the ethnoarchaeological research agenda. Some archaeological subdisciplines, such as zooarchaeology, have incorporated ethnoarchaeological research into their interpretive framework (Abe 2005; Costamagno and David 2009; Kent 1993; Monahan 1998; Sázelová et. al. 2015; Svoboda et. al. 2011; Waguespack 2002). Over the years, ethnoarchaeological research has also incorporated a microscopic scale of observation, as in the study of ethnographic artifacts as reference data sets for archaeological use-wear analyses (Beyries 1995; González-Urquijo, Beyries, and Ibáñez 2015; Mansur 1983). Despite these efforts, the ethnoarchaeological fire record is

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understudied, and the reason might be that fire residues are predominantly sedimentary in nature (ash and minute charred residues embedded in sediment) and the study of the sedimentary context in ethnoarchaeology is relatively recent, with only a few published case studies (see Friesem 2016 for a review on this topic).

In this paper we first briefly review and discuss the role of fire in ethnoarchaeological research applied to Paleolithic archaeology and then summarize and discuss two examples of our previous research on fire in ethnoarchaeological contexts. Our goal is to highlight the kinds of questions that can be addressed by studying the ethnoarchaeological record of anthropogenic fire and possible pitfalls. We also set forth a few methodological guidelines that, based on our experience in geoarchaeology and anthracology applied to ethnoarchaeological contexts, may aid in procuring useful ethnoarchaeological data toward an understanding of archaeological combustion structure formation processes.

Ethnoarchaeology and Paleolithic Archaeology: The Role of Fire

Why have the hearths of contemporary traditional societies not been studied in-depth to advance Paleolithic research? Ethnoarchaeological data have been an important source of information in Paleolithic archaeology, from Binford's exhaustive documentation on the Nunamiut of northcentral Alaska (Binford 1978) to other referential studies on hunter-gatherer societies around the globe (e.g., Beyries and Pétrequin 2001; Beyries and Vaté 2007; Brooks and Yellen 1987; Fewster and Zvelebil 2001; González-Ruibal, Hernando, and Politis 2011; Kelly 1995; Leroi-Gourhan and Leroi-Gourhan 1989; Lim 1985; O'Connell 1987; Peterson 1971, 1973; Pétrequin 1988). Traditional ethnoarchaeological data concern material and spatial aspects of human behavior analyzed with a holistic approach in order to understand the link between material culture and social structure and beliefs (Binford 1980:5).

Concerning fire, Binford set forth hypotheses about hearth function, such as in his interpretation of certain archaeological combustion features as smudge pits based on ethnoarchaeological observations (Binford 1967). He also used ethnoarchaeological data to approach areas of human activity and to identify some of the factors of archaeological assemblage formation (e.g., Binford 1978). For instance, ethnoarchaeology-based models such as Binford's "hearth-related assemblage," "toss and drop zone" (Binford 1978), or collector/forager models (Binford 1980) have been widely used to interpret intrasite archaeological spatial distribution patterns and to infer intersite Paleolithic settlement dynamics, respectively. Actually, the study of settlement dynamics elements such as territorial mobility or site type has relied heavily on ethnoarchaeological information (e.g., Binford 1980; Brooks and Yellen 1987; Cameron and Tomka 1996; Grøn 2005; Kuznetsov 2007).

On the whole, it is generally difficult to obtain detailed information about fire-related practices based on the existing published ethnographic/ethnoarchaeological works. Besides Binford's work, the ethnographic/ethnoarchaeological literature containing information on fire is mostly scattered within general works about the daily life of particular societies, and very few address technical issues of fuel selection and fire management. Nevertheless, cultural-ecological studies including fire as part of both symbolic and economical practices commonly provide examples of fuel type selection and management, fire functionality and techniques used in cooking fires, duration, spatial distribution, and the entity of group members in charge of fire in a number of published studies on such topics (e.g., Brandisauskas 2007, 2010; Gur-Arieh et al. 2013; Lavrillier 2005; Osgood 1970 [1936]; Picornell Gelabert, Asouti, and Allué Martí 2011; Sillar 2000).

Other factors—such as burning temperatures, hearth relighting, reworking of ashes, or charcoal dispersal and microanatomy—are less present in ethnoarchaeological accounts (with exceptions such as Ntinou 2002; Zapata Peña et al. 2003). Such factors, which are particularly significant in the interpretation of Paleolithic fire because they can be approached through the archaeological record, often emerge from questions raised by the study of the sedimentary archaeological record or the bioarchaeological record (i.e., charcoal and other organic residues) at microstratigraphic/microscopic scales of observation, which are generally overlooked in ethnoarchaeological contexts.

As pointed out by Goldberg and Macphail (2008) and more recently by Friesem (2016), geoarchaeology and bioarchaeology did not incorporate ethnoarchaeological investigations into their agendas until very recently. The application of geoarchaeology to ethnoarchaeological contexts, or geo-ethnoarchaeology (a term coined by Brochier et al. 1992), is a relatively young field with great potential for advancing our understanding of formation processes of archaeological sites and features. So far, there are few exploratory geo-ethnoarchaeological studies, and these have focused on the micromorphological and geochemical identification of activity area sedimentary indicators (e.g., Anderson et al. 2014; Brochier et al. 1992; Shahack-Gross, Marshall, and Weiner 2003; Shahack-Gross et al. 2004; Wattez 1992), post-depositional processes affecting household elements (Friesem et al. 2011, 2014*a*, 2014*b*; Goldberg and Whitebread 1993), and the sedimentary manifestation of different kinds of open-air hearths (Mallol et al. 2007).

Within the field of fuel analysis, a few studies have undertaken investigations of ethnoarchaeological contexts related to fire by focusing on different types of fuel, mainly dung and wood. Only the most recent ethnoarchaeological studies on the use of dung among traditional societies include sampling protocols that aim at producing reference data sets for identifying the use of dung as a fuel within archaeological cooking structures (Gur-Arieh et al. 2013; Lancelotti and Madella 2012; Lancelotti, Ruiz-Pérez, and García 2016).

Regarding wood fuel, even though the potential benefits of incorporating ethnoarchaeology into charcoal analysis were pointed out more than 20 years ago (Chabal 1994), "ethnoanthracology" (Henry 2011; Henry, Théry-Parisot, and Voronkova 2009) has only been applied to very few ethnographic charcoal assemblages (Henry and Théry-Parisot 2014*a*; Joly et al. 2009; Ntinou 2002; Vidal-Matutano 2013). The aims of such studies have been to assess the paleoecological accuracy of charcoal analysis and/or to explore the extent to which different methods are able to identify human practices.

In sum, although there have been ethnoarchaeological approaches to Paleolithic fire since the 1970s, these have rarely focused on combustion residues, which are direct transmitters of environmental and behavioral information. In recent years, with the prominence of interdisciplinary studies in archaeology, the anthropogenic combustion record in the ethnoarchaeological context is starting to be queried, and Paleolithic archaeology can largely benefit from such a source of analogy.

Research Avenues for the Ethnoarchaeological Study of Fire: Lessons from Previous Case Studies

Given an interest in hearths and hearth-assemblage formation processes, we aim at approaching some of the factors involved in the formation of archaeologically observable features formed throughout the depositional and postdepositional history of a hearth. Such features may include thermally altered sediment, artifacts and bone fragments, 1–5 cm layers of ash or carbonaceous matter, and concentrations of charcoal fragments of different sizes. In practice, this is no simple task. The ethnoarchaeological context is complex and might lend itself to infinite query. Also, every case study is unique in the kinds of human actions performed around fire as well as in the nature and condition of the local sedimentary substrate. Thus, it is likely that specific questions and analytical parameters arise not only in the beginning but also during the course of the investigation once the researchers are familiarized with the site. In the case of ethnoarchaeological fieldwork for the study of hearths, familiarization with the site includes gaining basic knowledge of the sedimentary context, that is, the substrate of anthropogenic fire. We point this out because ethnographic research does not usually focus on sedimentological descriptions.

The motivation underlying ethnoarchaeological research design may be (1) to test existing behavioral or taphonomic interpretations derived from archaeological or experimental data, which will likely involve specific questions and analytical parameters, or (2) to document the material expression of particular human actions and their modification through time, which may lead to open-ended, exploratory studies. In the following paragraphs, we provide two examples to illustrate both kinds of motivation and highlight some of the results and implications for each case.

The Hadza Study on Open-Air Hearths

The Hadza study (Mallol et al. 2007) was designed as a test of the visibility of previously established micromorphological features associated with anthropogenic fire (such as browning-reddening, fissuring, and soil organic matter carbonization) in days-old to months-old open-air hearths made by a group of Hadza foragers (Tanzania) and documented ethnographically. To this end, the ethnographers collected a series of undisturbed micromorphology sediment blocks from abandoned open-air, cooking, and sleeping hearths (fig. 1). Some of the hearths were recent (days old), while others had been abandoned for 1 year. Regarding the duration of these fires, some of them were continuously used for 3–4 months, while others were brief fires (less than an hour in duration) for roasting food items.

The results of this study, detailed in Mallol et. al. (2007), included field and micromorphological observations on the sedimentary substrate associated with the abandoned hearths. At a microscopic scale, all the samples, including those from hearths that had been abandoned for a year, yielded combustion residues (wood ash, charcoal, and charred plant/animal tissue) attesting to the presence of anthropogenic fire as well as microstructural sedimentary features such as matrix disaggregation and browning or "masked birefringence." Overall, the micromorphological components and features observed are in agreement with those proposed by Wattez (1992) as representative of moderate to high intensity hearths involving temperatures from 350°C to >500°C.

Certain micromorphological differences relating to function were observed among the different types of hearth. For instance, the sedimentary substrate of a brief fire made to roast an impala yielded a few amorphous black impregnations and coatings (fig. 2*A*), and a tuber-roasting fire left behind microscopic charred plant tissue fragments (fig. 2*B*). Before this study, it was unknown whether or not specific activities related to anthropogenic fire might leave microscopic material evidence in the sediment. Unfortunately, these particular hearths were sampled only days after they were made, and we do not know the preservation potential of the observed features. There were also micromorphological differences relating to taphonomic factors. The hearths sampled 1 year later showed presence of ash only in a case where a layer of dry grass from a dismantled hut had covered the hearth. They also showed signs of bioturbation (channels and fresh rootlets dissecting the top of the combustion structure; see fig. 2*C*), whereas those that were days or months old did not (fig. 2*D*). Interestingly, bioturbation did not affect the sedimentary fabric to the extent of precluding identification of combustion features.

The study also showed that micromorphology is a powerful tool to approach the genesis of sedimentary deposits through a very peculiar finding: one of the samples showed micromorphological features indicative of the presence of an abandoned hut floor beneath one of the open-air hearths. The previous existence of a hut at the spot of that particular hearth had not been reported ethnographically. This finding shows that geo-ethnoarchaeology performed at a microstratigraphic scale of observation adds a temporal dimension, thus contributing historical information. This contribution may help alleviate a shortcoming of ethnoarchaeology pointed out by Wobst (1978): "The ethnographic record is insufficiently sensitive to deal with be-

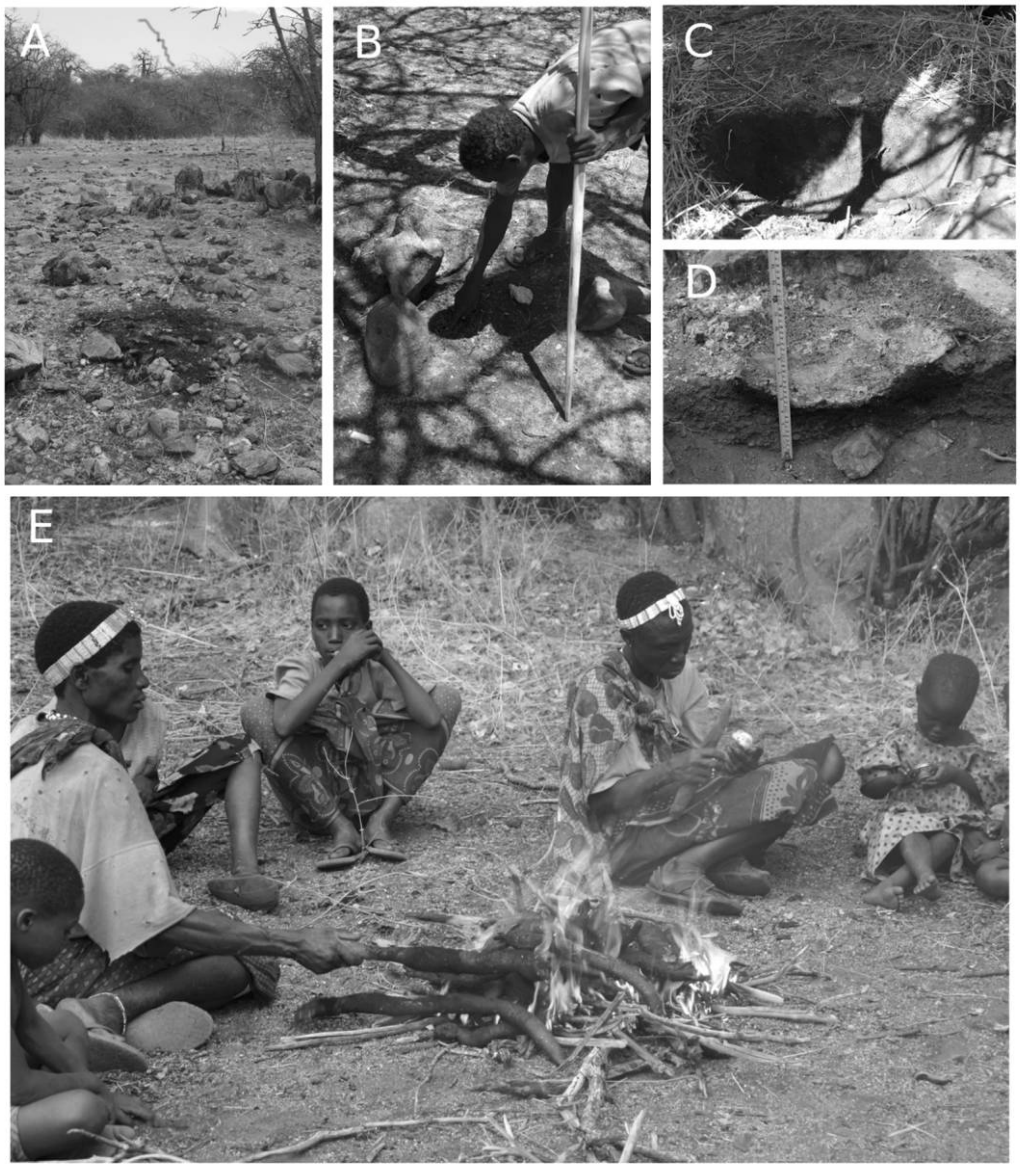

Figure 1. Different types of Hadza hearths subjected to micromorphological analysis. *A*, Brief, 20-minute-long fire used to burn an impala and sampled 10 days later. *B*, Cooking hearth used recurrently for 4 months and sampled a year later. *C*, Abandoned sleeping hearth at the entrance of an abandoned hut. It was lit every night for 4 months, and the sample was collected a year after abandonment. Note the layer of dry grass over it. *D*, Communal cooking hearth used continuously for 3 months and sampled 2 months later. *E*, Brief (15 minutes) tuber-roasting fire that was sampled the day after. A color version of this figure is available online.

havioral variability. The living social context is complex and we can only attempt to perceive a limited range of its material expressions." By incorporating historical information, we broaden the scope of possibly interrelated material expressions.

Overall, our results provided an example of what different kinds of simple anthropogenic fires might leave behind in ethnographic contexts after up to a year's time. In this regard, the results suggest that rates of sedimentation and the effect of postdepositional disturbance factors such as bioturbation or erosion are key factors in the preservation of open-air simple hearths. Erosion by rain and deflation seemed to be particularly influential, as we saw that the ash layer of a hearth that had been protected by a light grassy cover was still intact after a year in the open-air while those of exposed hearths had disappeared, or that the ash of a 10-day-old hearth dissipated after a single rainfall event. The Hadza example also showed that even though the ash component is likely to erode away with time in cases of low sedimentary rates and deflation, the irreversible effects of fire in the top 2 cm of the sedimentary substrate (charring of soil organic matter and clay alteration) may remain intact and be readily identified through micromorphology.

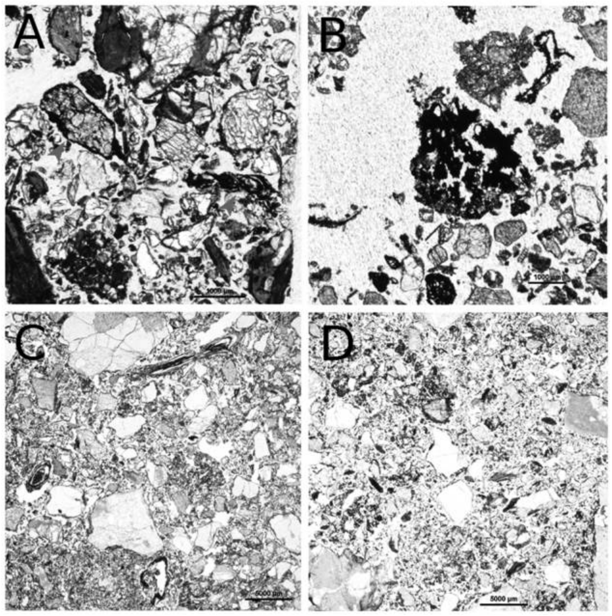

Figure 2. Microphotographs from thin sections of different Hadza hearth samples. *A*, Detail of the topsoil in a brief impala-burning hearth sampled after 10 days showing thin black coatings and cappings on some of the rock fragments. *B*, Detail of the topsoil in a brief tuber-roasting hearth sampled after 1 day showing the presence of charred plant tissue fragments (black particle at the center and smaller ones around it). *C*, Topsoil of a 1-year-old cooking hearth. Note the compact appearance and presence of rootlets. *D*, Topsoil of the impala-roasting hearth. Note its loose appearance and lack of rootlets, channels, or other bioturbation features. A color version of this figure is available online.

All these observations can be useful in the interpretation of Paleolithic fire evidence. Unfortunately, micromorphological studies of Paleolithic open-air combustion features are scarce. The bulk of data was gathered by Wattez in the 1990s and is associated with Upper Paleolithic and Mesolithic open-air hearths, which are generally more complex, involving stone-lined or stone-filled pit structures (e.g., Wattez 1992, 1994). Therefore, there is not much data allowing us to make analogies with the results of our study of simple Hadza hearths. One case is the Middle Paleolithic open-air site of Nesher Ramla, Israel, where an in situ simple combustion structure and a wood ash midden were reported by Friesem, Zaidner, and Shahack-Gross (2013). The sediments from the combustion structure showed a thin black layer composed of blackened sediment aggregates overlain by wood ash residues and calcined bone fragments (Friesem, Zaidner, and Shahack-Gross 2013).

According to the authors, preservation of these features was possibly enhanced by their location in a topographic depression sheltered from the wind and receiving regular colluvial input, which would have buried the intact features. This interpretation is in agreement with our observations from the Hadza hearths, as we would not expect long-term preservation of ash in such simple open-air combustion features otherwise. The amount of ash reported for the in situ hearth at Nesher Ramla is quite small, suggesting either some period of deflation or erosion from rain before burial. Regarding the charred substrate, the presence of blackened soil aggregates suggests a more organic-rich substrate than what we documented in the Hadza study, which was practically barren land with a light grass cover.

In sum, the Hadza study showed the value of performing high-resolution, microstratigraphic investigations of the ethnoarchaeological sedimentary record to distinguish between natural and anthropogenic fire, to estimate burning intensities, to identify fuel types, and to assess preservation potentials. In hindsight, the study would have yielded more detailed results if we had included the following items in the research design: (1) the presence of a geoarchaeologist on site to enrich the ethnographic record with data relevant for the study of site formation, and (2) the implementation of techniques complementary to soil micromorphology. Current geoarchaeological combustion structure investigations are normally carried out from a microcontextual perspective using interdisciplinary microstratigraphic methods (see examples in Mentzer 2014) and involving techniques from inorganic and organic geochemistry and geophysics, including, for example, organic petrology for identification of microscopic charred particles, Fourier Transform Infrared Spectrometry for mineral identification, gas chromatography mass spectrometry for lipid analysis, or archaeomagnetism to approach firing temperatures and temporal relationships between different hearths. Applying such techniques in the Hadza study might have strengthened the reliability of such techniques to provide data on thermal alteration of the substrate and to identify combustion residues.

Finally, in order to further expand the results obtained in the Hadza study toward an understanding of Paleolithic combustion structures, the results need to be tested against experimental taphonomic data on abandoned open-air hearths and also against micromorphological data from ethnoarchaeological examples of hearths in enclosed settings (caves or rock shelters) as well as examples of superimposed and imbricated hearths, which are common in the Paleolithic fire record. No such data are currently available.

The Evenk Study of Specialized Open-Air Hearths

The Evenk research program was first designed as a case study to test a model proposed for the European Paleolithic according to which fuel management is a complex system resulting from a series of interacting environmental and cultural parameters (Théry-Parisot 2001). An exploratory study was carried out among a group of Evenk reindeer herders and hunters from the Amur Region (South Eastern Siberia) in order to (1) observe firewood management practices from wood acquisition to the discard of fuel residues; (2) observe possible connections between the environment (available biomass), human activities, and fuel management; (3) assess which of these observations could be evidenced by the study of anthracological remains and sedimentary micromorphological signatures; and (4) explore the possibility of tracing analogies between current nomadic lifeways in cold environments and Paleolithic contexts (Henry 2011; Henry and Théry-Parisot 2014*a*; Henry, Théry-Parisot, and Voronkova 2009).

Fieldwork among the Evenks was carried out in two seasons, one in late winter/early spring, and another in late summer/early autumn. Throughout the study, we observed that Evenk traditions are strongly influenced by seasonality and residential mobility. These factors have a decisive effect on the range and configuration of activities performed at their camps (which in archaeological terms would determine the site's function). This observation also applies to combustion structure types, their function, and firewood management, with wood procurement areas and modalities varying according to the time of year (Henry 2017; Henry, Théry-Parisot, and Voronkova 2009). In turn, combustion structure types and functions determined the species and state of the selected wood. In Paleolithic research, seasonal constraints have mainly been approached through subsistence studies. By showing that a whole range of activity areas—firewood management included—are strongly tied to seasonal and climatic conditions, this example invites us to expand our approach of seasonality, prehistoric settlement patterns, and mobility.

Furthermore, the study confirmed the positive correlation between the degree of fuel selectivity and of hearth specialization implicitly suggested in earlier anthracology works (Chabal 1982, 1991) as well as the importance not only of the taxon but also of the state of the wood in the wood selection process (Théry-Parisot 2001). In turn, the implications for prehistoric anthracology are that the identification not only of the taxon but also of the state of the wood used is crucial for the characterization of prehistoric wood procurement modalities, combustion behavior, and the specialized/seasonal nature of the hearths (see also Henry and Théry-Parisot 2014*b*; Théry-Parisot and Texier 2006).

Finally, the relationship between two kinds of fireplaces and anthracological/micromorphological signatures were explored during the second field season, in which our Evenk hosts were kind enough to allow us to collect charcoal from a smudge fire and to excavate and sample their hide-smoking hearth for charcoal and micromorphological analyses (fig. 3). We excavated half of it, collecting anthracological samples, and saved the other half for micromorphological sampling, which required dismantling of the hearth.

Micromorphological observation of three thin sections from the hide-smoking hearth, which produced no ash, showed that the combustion deposit consisted of a mix of charcoal and 1–3 cm fragments of rotten wood without any visible signs of burning on a bed of relatively fresh plant litter (fig. 4). A few rotten wood fragments were also observed embedded in the plant litter layer (fig. 4*A*). Rotten wood has a low preservation potential under aerobic conditions. Thus, encountering such evidence in archaeological context is infrequent, and we can assume that identifying the presence of residual rotten wood in an archaeological version of this hearth would require investigations at a molecular scale. The same can be said about the substrate, which consisted exclusively of fresh plant litter without any apparent effects from the overlying combustion. This is explained by the way in which the fire was made: a small quantity of charcoal from sound wood was produced in a furnace elsewhere and redeposited on the ground at the hide-smoking spot, where it was then covered by rotten, crumbling wood.

Interestingly, our microscopic observations suggest that similar hide-smoking hearths might have been previously made at the same place, as indicated by the presence of rotten wood—an intrusive element brought by humans—contained within the plant litter substrate. As in the Hadza case, micromorphological analysis yielded information on past events. As we know from the Evenks we worked with, they normally return to their main campsites yearly, at least for periods of 4–5 years, and light their fires at the same spots as in previous occupations.

In sum, we can predict that a possible archaeological expression of a hide-smoking combustion structure of the kind studied here, after many years of subaerial exposure, would exhibit a very weak sedimentary signature consisting of a diffuse layer of charcoal resting on an unburned sedimentary substrate.

Regarding our anthracological results, both hearths (smudge fire and hide-smoking hearth) were positively discriminated and allowed us to set forth a new method to diagnose the initial soundness of firewood based on the identification of micromorphological fungal alteration intensities observed on charcoal fragments (Henry and Théry-Parisot 2014*a*; fig. 5). This method has proven to be effective for discussing fuel management strategies evidenced in Paleolithic and Mesolithic hunter-gatherer sites (Henry and Boboeuf 2016; Henry and Teten'kin 2014; Vidal-Matutano, Henry, and Théry-Parisot 2017).

These results have several implications for Paleolithic anthracology because they evidence the nature of the link between environmental conditions, lifeways, and modalities of fire use. As in other research domains, comparisons with other ethnographic settings point at the great variability of practices and beliefs around fire. Nevertheless, regularities also exist between different groups, revealing similar choices under comparable environments (Henry 2011). For example, the use of crumbling, rotten wood for smoking hides is ubiquitous among northern hunter-gatherers living in forest environments from Siberia to North America (Alix and Brewster 2004; Anikhovskij et al. 2012; Beyries 2002, 2008; Binford 1967; Brandisauskas 2007, 2010; Henry, Théry-Parisot, and Voronkova 2009; Lavrillier 2007; Nelson 1986; Osgood 1970 [1936]). The prospect of being able to discuss archaeological hearth functions thanks to new developments in ethnoanthracology is particularly exciting and motivates new archaeoanthracological studies geared in this direction. One such study involves a hypothetical Middle Paleolithic smoking hearth based on archaeoanthracological data (Vidal-Matutano 2016; Vidal-Matutano, Henry, and Théry-Parisot 2017).

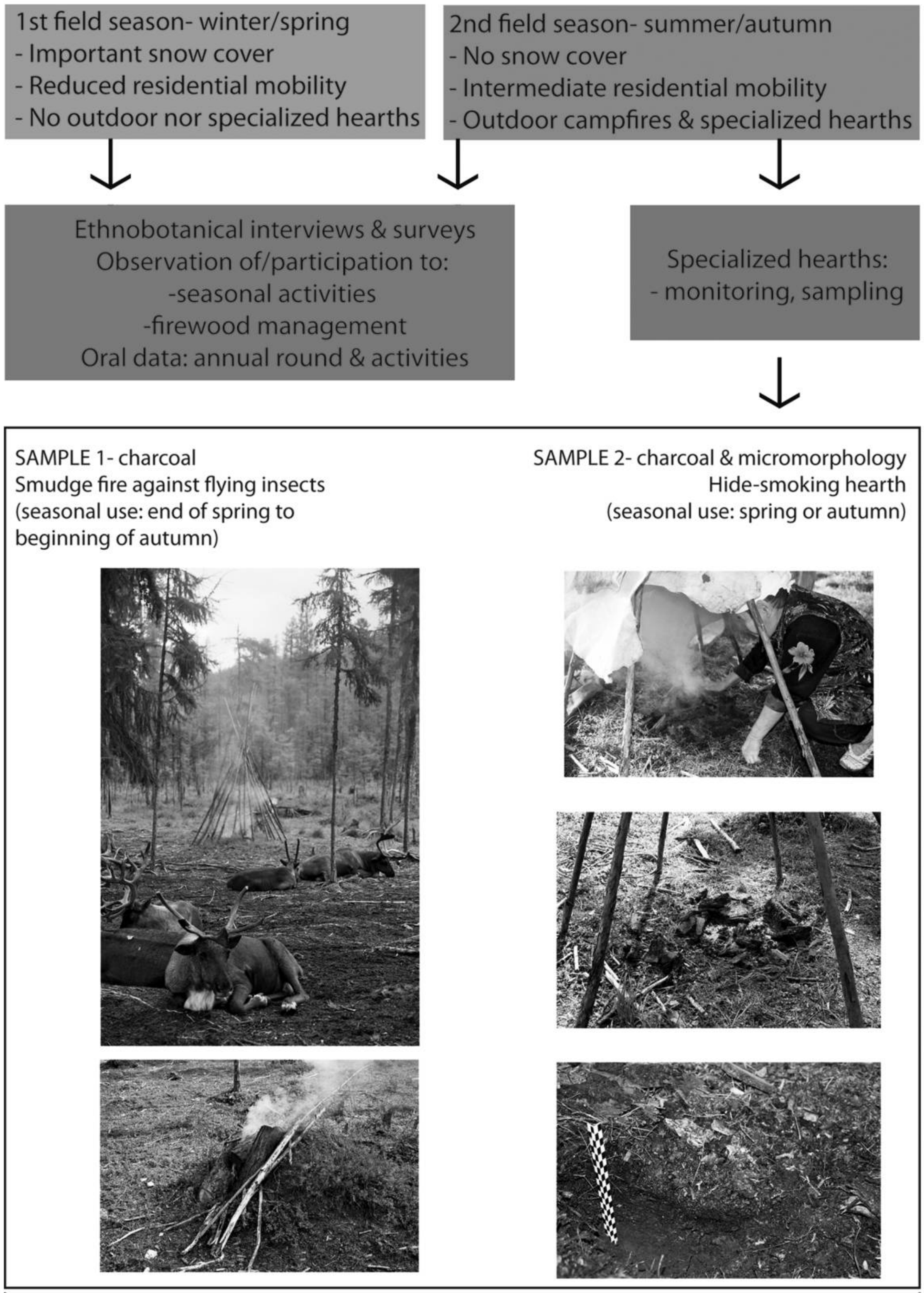

Figure 3. Summary of the ethnoanthracological work with Evenki from Ulgen, Amur Region. Photos: Auréade Henry, ACI "Système Renne." A color version of this figure is available online.

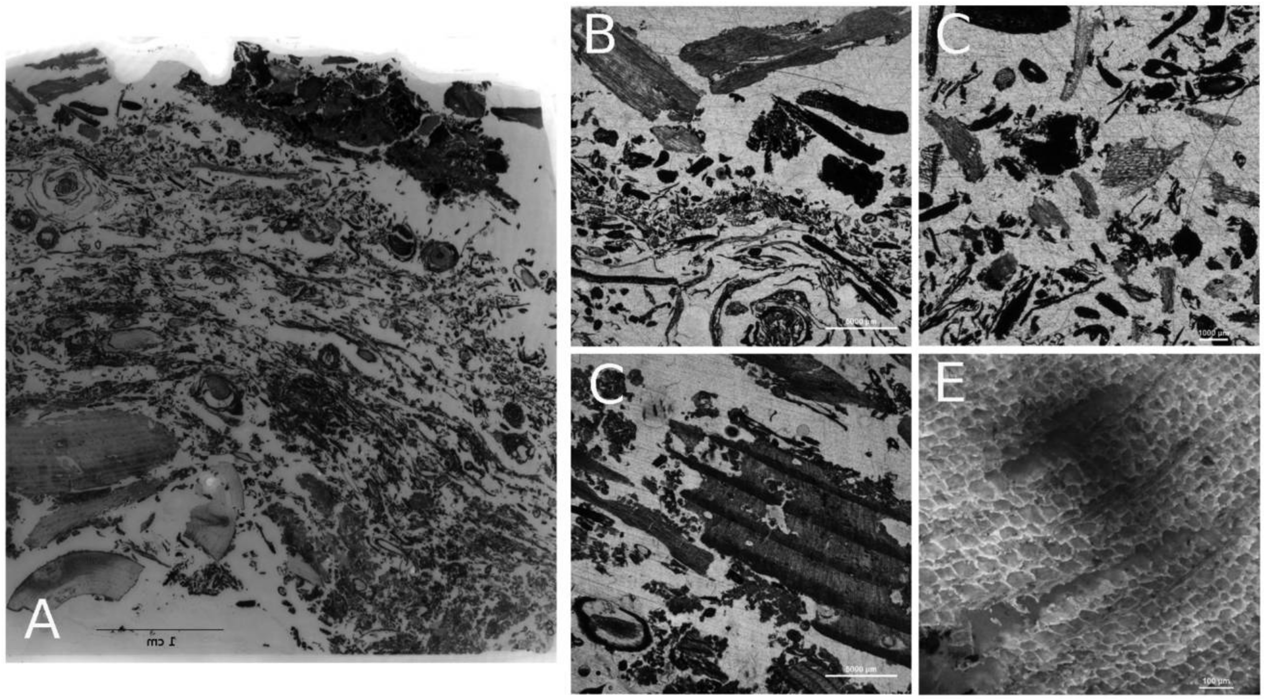

Figure 4. *A*, Scan of thin section from micromorphological sample collected from an Evenk hide-smoking hearth. Note the presence of rotten wood fragments (lighter colored) at the top but also embedded within a plant litter deposit. *B*, *C*, Microphotographs from the same thin section and two others showing a mixed presence of charcoal (dense, black particles) and rotten wood fragments (yellowish-brown particles) on a pristine bed of plant litter (lower half of image in *A*). *D*, Rotten wood fragment. Note the presence of fecal pellets (small granules filling gaps between healthy portions of tissue). *E*, Detail of rotten wood fragment showing deformed cell walls due to fungal attack. Photos taken in Plane Polarized Light; *E* taken in Blue Light (400–440 BL). A color version of this figure is available online.

The downside of the Evenk study is that the limited amount of hearth samples is insufficient to fully evaluate the potential and limitations of our results. Also, as with the Hadza study, applying complementary geoarchaeological techniques would have allowed for richer, more robust data. In the future, many more hearths need to be sampled in order to obtain a stronger reference data set and establish a protocol that incorporates multiproxy geoarchaeological and bioarchaeological data.

A final observation is that studying hearths that are still in use has many advantages, because complete operational chains (*chaînes opératoires*) of specific activities such as meat curing or hide smoking can be documented as well as their timing and duration, fuel amounts and procurement distances, and other such variables involved in fire technology. However, one disadvantage is that sampling can be difficult or even impossible because it involves destruction of a structure within or outside the perimeter of ongoing domestic activity. Some of these structures may have a strong cultural or symbolic meaning for the community.

Methodological Guidelines

The two examples presented here convey a series of aspects to take into consideration when designing an ethnoarchaeological project to study contemporary simple hearths comparable to Paleolithic counterparts. Among the things to consider are planning for the implementation of interdisciplinary methods to test the preservation state of the target features before intervention. In this section, we provide a few more specific and practical guidelines that may facilitate the research design.

1. Compile ethnographic data and assess their quality. What is the potential of this data to address archaeologically relevant questions regarding anthropogenic fire? When a pertinent research context has been defined, it is equally important to assess the marginality of the recorded activity or process: is this type of behavior recurrent today among traditional societies and at what scale? What other related social and environmental domains need to be described?
2. In the case of abandoned contexts, which may be exposed or buried, assess the degree of integrity of the record through surveys and test pits. For each proxy, control samples from nearby natural deposits or activity areas should also be collected to validate the diagnostic value of the results.
3. Perform excavation and collect sediment samples for multiple microstratigraphic analytical techniques. Unlike other ethnoarchaeological remains, such as exposed remains, combustion structures representing open hearths

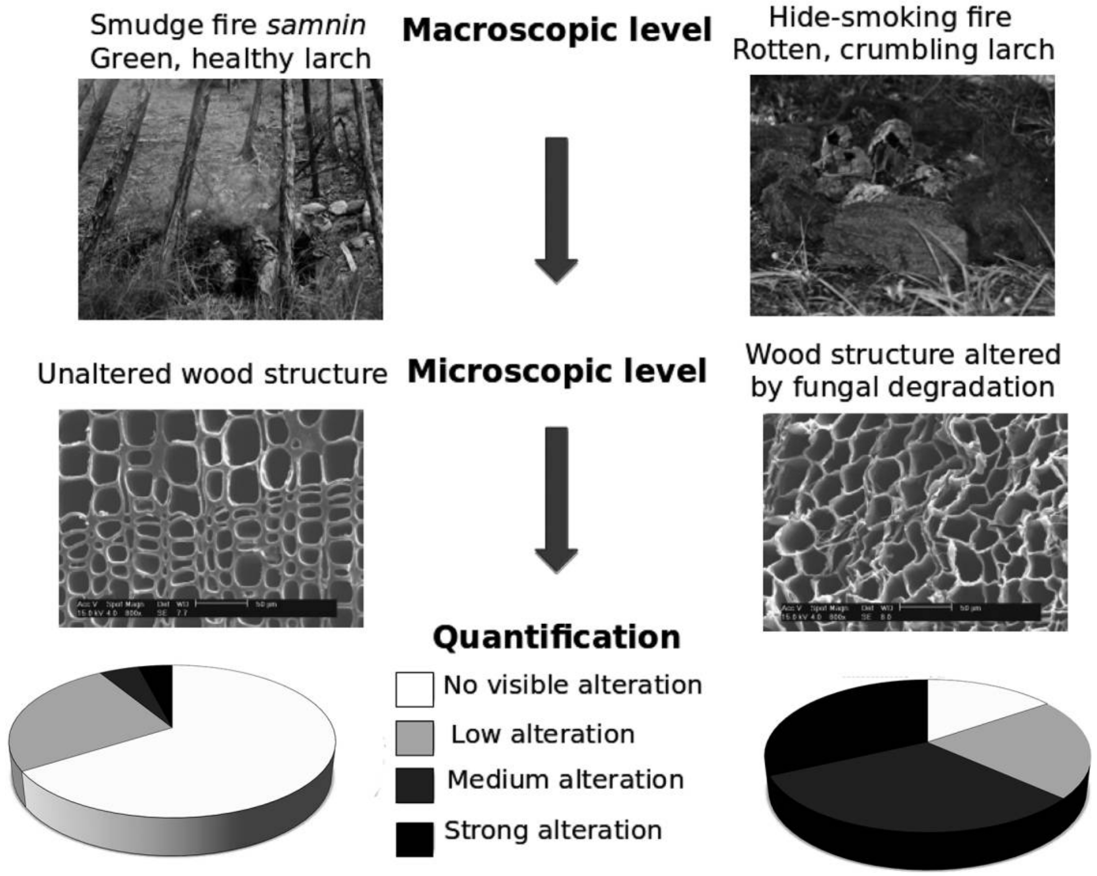

Figure 5. Differences in the proportions of microscopic fungal degradation features on charcoal samples according to the initial soundness of the wood used in the fire. Photos: Auréade Henry, ACI "Système Renne." The SEM photos were taken for A. Henry by Monique Repoux, Centre de Mise en Form des Materiaux, Sophia Antipolis, France. A color version of this figure is available online.

always require excavation because of their sedimentary nature. Excavation and sampling may be performed following a protocol for archaeological combustion features. We propose to follow these steps (fig. 6):

a. Determine the perimeter and plot it within a coordinate system.
b. Divide the feature in two equal portions and excavate half of it, leaving the other half for microstratigraphic sampling. Excavate following stratigraphic layers and place the sediment from different layers in different bags. If possible, collect all the sediment for future studies on fuel loss, ash yield, etc. This sediment will be subsequently sorted to recover different kinds of macroremains (charcoal, seeds, bone fragments, microfauna, etc.). In cases of occurrence of anthropogenic bone remains other than fuel or artifacts, these should be plotted as material remains within the coordinate system, including their depth.
c. While collecting samples from the second half, keep all the remaining sediment and piece-plot any artifact, bone, or other visible anthropogenic object. Keep in mind that different analytical techniques (e.g., soil micromorphology, organic and inorganic geochemistry, archaeomagnetism, analysis of phytoliths, spherulites, and pollen if applicable) require different specific sampling protocols.
d. Collect control sediment samples (or hand specimens in the case of macrobotanical studies) from outside the combustion structure for each of the analytical techniques.

Discussion: Some Pros and Cons of Ethnoarchaeological Research to Approach Paleolithic Fire

Ethnoarchaeology may be viewed as a polemic field of research because at first it seems rather impossible, if not dangerous and unscientific, to use ethnographic data for the interpretation of archaeological evidence. Societies are complex dynamic systems fashioned by multiple interrelated factors across space and time. Some authors are pessimistic about the potential of ethnoarchaeology unless it is carried out through an ontological approach (González-Ruibal, Hernando, and Politis 2011).

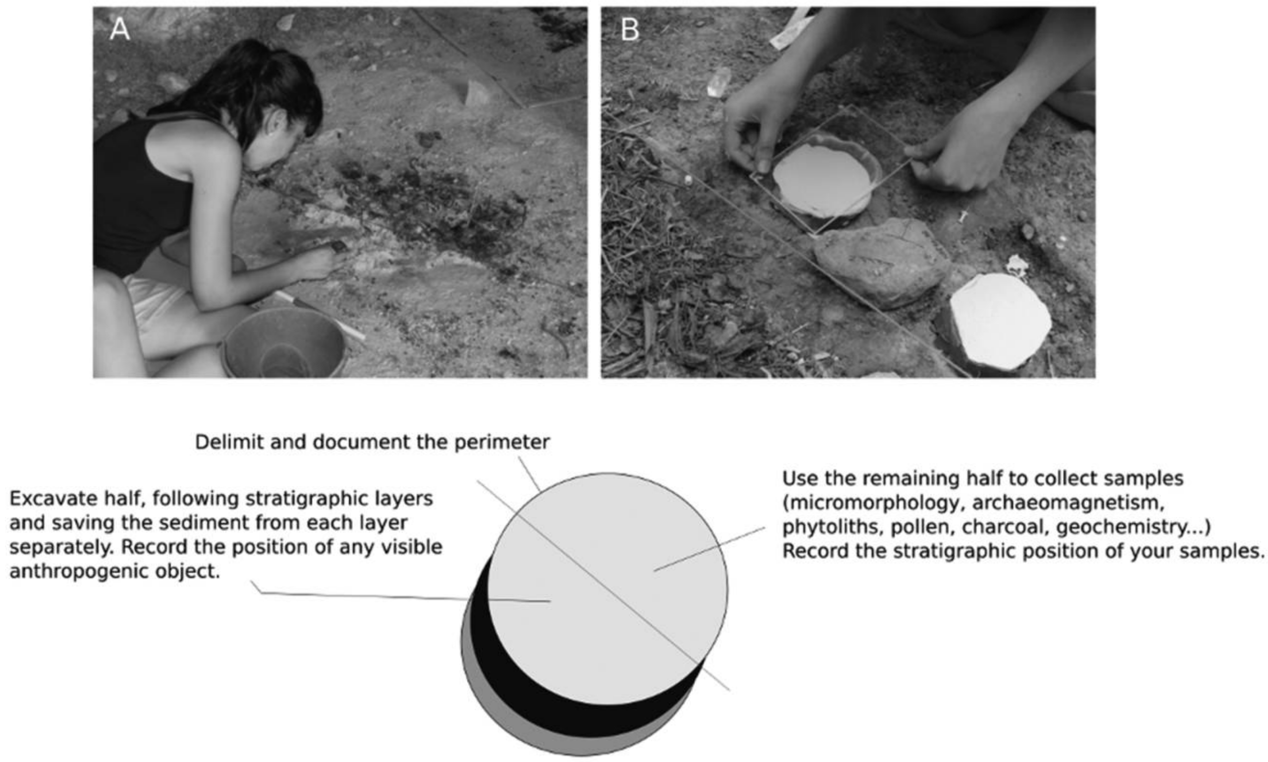

Figure 6. *A*, Excavation of a recent cave entrance hearth. Note that the excavator is reserving half of the combustion structure for sampling. The location of two micromorphological samples in the other half has been marked with nails and thread. *B*, Archaeomagnetic sampling of half of a 5-year-old combustion structure. A color version of this figure is available online.

In practice, this means that in the study of a particular aspect of human behavior, such as behavior around fire, researchers need to adopt a broad perspective and include other behavioral domains in order to approach more general aspects of societal and/or environmental value. In other words, anthropogenic fire, as any other element of human social behavior, must be considered within its social and environmental context. Thus, ideally, the ethnoarchaeological research team involved in a study of fire behavior should include experts from different fields documenting as many aspects of culture and environment as possible.

Another polemic issue is the validity of ethnographic analogy. Present-day observations should not be directly transposed to the past. Caution should be taken when using contemporary societies to approach distant spatio-temporal contexts (e.g., comparing present-day subtropical agricultural societies with Paleolithic hunter-gatherers of the Northern Hemisphere) or tracing analogies that may seem straightforward (e.g., Bronze Age vs. present-day traditional pastoral societies of the same area). In all cases, it is important to bear in mind that "the true role of ethnoarchaeology is not to provide the prehistorian with analogical tidbits, but rather to be an important source for those wanting to build theoretical models for the relationships between people and things" (Skibo 2009:47). As shown by our own work, ethnoarchaeology also provides insight into site formation processes and the nature of our archaeological remains (including sedimentary residues).

The challenge lies in achieving ethnoarchaeological research design in a way that meets the standards of current archaeological science. There are very few general works on ethnoarchaeology (e.g., David and Kramer 2001) that include methodological guidelines geared at multidisciplinary research and the incorporation of subdisciplines such as bioarchaeology and geoarchaeology. Despite this, the existing literature reveals that ethnoarchaeology may truly benefit most fields of prehistoric research as long as two main targets are pursued: (1) obtaining contextualized ethnographic data through interdisciplinary approaches and (2) carrying out research motivated either by archaeological facts and questions or by a need to obtain reference material for the material residues of specific human activities or lifestyles.

According to our personal experience in the field of the ethnoarchaeology of fire, it has become obvious that ethnoarchaeology is much more than a "real-size experiment." Ethnoarchaeology not only improves our reference data sets (and in this sense, it is complementary to experimentation) but also provides an enriching way of approaching the archaeological record through the possibility of apprehending the diversity of environmental and societal variables and their effect on the material record.

The Hadza and Evenk studies are good examples of how ethnoarchaeological research may generate new knowledge that is complementary to archaeology and experimentation. In the Evenk case, while showing that the archaeological model was easily adaptable to any fuel management study, our observations also revealed complex patterns of human behavior toward firewood, which could only be understood in regard to the social, economical, and seasonal background of the study. In return, these results provided us with new ideas for interpretative pathways of prehistoric fuel selection and hearth function in relation to site function and seasonality.

The challenge was then to test the potential of archaeometric methods to document socioeconomic aspects through the study of their material expression: combustion structures. The positive results of the ethnoanthracological analysis, which have been subsequently validated by substantial experimental replication (Henry and Théry-Parisot 2014*a*), opened up new methodological perspectives on fuel selection, hearth function, and even seasonality.

In sum, ethnoarchaeology is complementary to but not replaceable by experimentation, because functional and meaningful anthropogenic deposits or sedimentary features are difficult if not impossible to produce outside their traditional context. On the other hand, experimentation can and should be used to further investigate and validate ethnoarchaeological results before testing their applicability to archaeological contexts. At a broader, systemic scale, ethnoarchaeology of fire is a powerful tool to evaluate the variability of human adaptations to the natural environment through the establishment of causal relationships between culture and fire technology.

Conclusions

This holistic, multidisciplinary approach, which allows us to take into account many different environmental and material and nonmaterial parameters influencing the nature of the anthropogenic combustion remains, aims at contributing to the development of new analytical methods for the study of prehistoric combustion structure formation processes, fuel management systems, and hearth function. We have shown that ethnoarchaeological research, whether motivated by the need to test experimental or archaeological interpretations or by exploration, requires case-specific questions and analytical parameters. Our two case studies are examples of the great potential in applying geoarchaeological and bioarchaeological techniques and have allowed us to identify several important factors that should be taken into account in future research design. These include the presence of specialists on site and application of multitechnique microstratigraphic studies.

So far, our work has provided pilot micromorphological and anthracological data that contribute to the study of Paleolithic fire. However, it needs to be expanded significantly in different ways. We now have a few examples of open-air hearths that need to be complemented with examples of hearths from enclosed settings such as caves and rock shelters and enriched by geoarchaeological and bioarchaeological data from additional techniques. It is to be hoped that further research of this kind will be carried out in the coming years and that it will contribute data to aid in building robust reference data sets for our understanding of Paleolithic hearth and hearth-assemblage contexts through ethnographic analogy.

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