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Geo-ethnoarchaeology of Fire: Geoarchaeological Investigation of Fire Residues in Contemporary Context and its Archaeological Implications

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**ABSTRACT**

Geoarchaeology focusing on microscopic and chemical remains has contributed greatly to the study of archaeological fire. One of the methodological approaches geoarchaeologists have adopted in the last two decades is the use of ethnoarchaeology to collect reference materials and construct models for how fire residues are formed and preserve or deteriorate in the archaeological record. Geo-ethnoarchaeology uses contemporary contexts to investigate both living and recently abandoned sites in order to directly link human behavior with the formation of microscopic and chemical markers and to follow the post-depositional processes, which affect the formation of the archaeological record. This article reviews the contribution of geo-ethnoarchaeology to the study of archaeological formation processes associated with fire residues through the examination of several key case studies and their archaeological implications.

**KEYWORDS**

Geoarchaeology; ethnoarchaeology; fire; micromorphology; FTIR; elemental analysis; phytoliths

**Introduction**

Human use of fire is considered one of the hallmarks of human technology. Pyrotechnology have attracted a lot of archaeological interest as the use of fire evinces developed skills and knowledge as well as a wide range of behaviors from technological to social ones. However, the archaeological identification of fire is not always simple (Mentzer 2014; Goldberg, Miller, and Mentzer 2017). When burnt, organic matter transforms mostly to ashes and charred materials, which do not always preserve well in the archaeological record. At the same time, burning also alters more durable materials such as minerals that are found in sediments and plants, bones and rocks (Weiner 2010). Archaeological research of fire residues is carried out mainly on charred remains by anthracologists and on inorganic materials (e.g. minerals and chemicals) by geoarchaeologists (Goldberg and Macphail 2006; Goldberg, Miller, and Mentzer 2017). In recent decades a major focus of geoarchaeological research has been devoted to the study of archaeological site formation processes (Goldberg and Macphail 2006). In the case of archaeological fire, geoarchaeology aims at understanding how human activities resulted in the deposition...
of burnt materials as well as how taphonomic post-depositional processes alter, deteriorate or preserve certain residues.

The contribution of ethnoarchaeology to the archaeological research is based on the wealth of information provided by the living contexts about the intangible social and material aspects that produce archaeological remains. In other words, by observing the formation of material remains related to human activity as it happens, ethnoarchaeology allows to directly link specific types of human behavior and their cultural meaning to archaeological formation processes (David and Kramer 2001; Friesem 2016). In that sense, the ethnoarchaeology of fire provides an important source of data for understanding pyrotechnology in its broadest sense and meanings. It provides important reference material for the archaeological investigation and interpretation of fire use (Mallol and Henry 2017). In this article, I review how geoarchaeological studies conducted in contemporary contexts provide valuable data in order to construct a reference framework for the study of archaeological microscopic fire residues.

**Geo-ethnoarchaeology**

The aim of geo-ethnoarchaeology is to study both the anthropogenic and natural agents that affect the formation processes of archaeological materials (Friesem 2016). To do so, geoarchaeologists sample remains from contemporary traditional settlements where they can document human activity as it happens and directly link specific types of behavior with the formation of a microscopic signature. In addition, studies have also been conducted in recently abandoned settlements (Shahack-Gross, Marshall, and Weiner 2003; Goodman-Elgar 2008; Friesem et al. 2011, 2014a, 2014b, 2016), where detailed information regarding human activity is available from living informants or detailed historical records. Recently abandoned sites mimic a near-archaeological context where taphonomic processes can be identified and the post-depositional mechanism can be studied. This unique combination of a geoarchaeological analysis augmented by ethnographic data is invaluable for the construction of a reference library that can be used for the interpretation of the archaeological record.

In order to study how archaeological fire residues were deposited and the mechanism behind their preservation, the entire process of formation needs to be tracked. Ethnoarchaeological studies of fire used ethnographic observations and interviews to document how people utilized different fuel materials and fire installations as well as how combustion features are operated, maintained and cleaned (Mallol and Henry 2017). Geo-ethnoarchaeological studies of fire further contributed a microscopic perspective showing how specific behaviors associated with the use of fire result in the deposition of microscopic and chemical residues. An important part of geo-ethnoarchaeological studies lays in the investigation of the taphonomic and post-depositional processes that affect the preservation of fire residues in different environments.

**Case studies**

It is not within the scope of this article to describe all the works and analytical methods used to study fire residues in ethnoarchaeological contexts. Below I choose to describe only a few key studies that illustrate the breadth, limitations and advantages of geo-
ethnoarchaeology to the study of fire residues from prehistoric and protohistoric contexts to domestic and urban ones.

**Foragers and open fires**

Hominins have been foraging for their subsistence for millions of years before the emergence of farming during the Late Pleistocene – Early Holocene transition. The investigation of forager use of fire is particularly challenging as these groups often use ephemeral open-air fires. The challenges of recognizing Paleolithic combustion features associated with hunter–gatherers (Goldberg, Miller, and Mentzer 2017) encouraged geoarchaeologists to understand the formation processes of fire residues associated with foragers in an ethnoarchaeological context.

A geo-ethnoarchaeological study by Mallol et al. (2007) was pioneering in its focus on fire. Following ethnographic work among the Hadza, a hunting and gathering society in East Africa, their aim was to assess the prospects for tracing the sedimentary components of ephemeral hearths and the ability to identify them in archaeological contexts. During fieldwork among the Hadza Mallol et al. (2007) documented the location of five open fires, the type of fuel, the fire function, and its duration as well as the time from abandonment to sampling. The hearths were sampled between ten days to a year after their abandonment. Sediment block samples collected from the five hearths were analyzed using soil micromorphology. The analysis showed that open-air fires sampled days after abandonment presented a good state of preservation to the extent that even a short duration of use (e.g. 15–20 minutes) left indicative fire residues in the form of calcitic ash, charcoals and altered soil substrate. On the other hand, when sampled after a year from abandonment, regardless of the duration of use, only a few carbonized organics on a reddened substrate could be traced. Mallol et al. (2007) argued that the poor preservation of fire residues is due to taphonomic processes namely wind and rain erosion alongside the disturbance of the sediments due to root activity. By comparing the preservation of fire residues in different localities, they concluded that when hearths were protected from the elements, for example when located inside huts or other shelters, they presented better preservation of indicative burnt features. This study highlighted the challenges to interpret forager use of open fire due to its ephemeral nature and the destructive post-depositional processes.

In a more recent study, Friesem et al. (2017) studied the use of fire among the Nayaka people, a contemporary hunting and gathering society living in the tropical forests of the Western Ghats hills in South India. Following ethnographic work among the Nayaka, two open-air sites and one rock-shelter, which were abandoned for 20–30 years by the same group of people, were excavated and sampled for geoarchaeological analysis (Figure 1). The aim of the study was to investigate how forager use of space can be detected archaeologically through microscopic analysis. In addition, a major part of this research was devoted to study the mechanism of site formation processes in the humid tropical environment (Friesem et al. 2017; Friesem and Lavi 2017). Focusing on fire residues, Friesem et al. (2017) presented ethnographic data demonstrating the association of social notions such as sharing, immediacy and mobility with Nayaka use of fire. Hearths were reported to be located only outdoor in full visibility of the other members of the hamlet. The Nayaka people’s wish to share things, actions and space with as many members of the group as possible, makes them to frequently change their locations and their activity areas within
As a result, hearths were erected and abandoned frequently, ever-changing their location reflecting the social dynamics at the settlement (Friesem et al. 2017). Small branches and twigs were collected daily from the forest and used as fuel (Figure 1(a)). The hearths were not reported to be specifically constructed and, although usually burning throughout the night, they were constantly kept at low fire intensity. Friesem et al. (2017) pointed out that only a low signal of partly charred wood, charcoal and ash could be traced after the fire died (Figure 1(b)). Excavating recently abandoned sites, Friesem et al. (2017) reported that fire residues were only found in situ in the rock-shelter where they probably represent the last episode of fire before abandonment (Figure 1(c,d)). Their post-depositional preservation is argued to be associated with the protection from wind and rain erosion offered by the shelter. An important observation made during the ethnographic work was related to the daily routine of raking-out and sweeping the hearths, which cleared the primary location from most fire residues.
(Figure 1(e)) and re-deposited them in waste areas (Friesem et al. 2017; Friesem and Lavi 2017) (Figure 1(f)). The excavation of two open-air sites did not yield evidence for fire residues in the main activity area. However, microscopic residues were found in secondary context in the waste areas, where activity remains were re-deposited by the sweeping and rapid rate of accumulation promoted higher preservation (Figure 1(g,h)). Taphonomically, the geoarchaeological analysis showed rapid dissolution (within a few weeks of abandonment) of calcitic ash remains and bones. Friesem et al. (2017) argued that the acidic conditions (pH < 7) in a humid tropical forest environment cause carbonates (e.g. ash and bones) to dissolve rapidly and completely, while under such conditions charcoal, phytoliths and certain elements indicative of fire residues (mostly P and Mg, and to some extent Sr) are preserved. Intensive biological activity within the forest sediments was reported to disturb the sedimentary sequence and to challenge the preservation of fire residues as well as the identification of primary activity contexts. Overall, by using infrared spectroscopy, soil micromorphology, phytolith and elemental analysis Friesem et al. (2017) demonstrated that although the natural conditions in humid tropical environment hamper the good preservation of fire residues it was still possible to detect microscopic markers, and to associate them with specific deposition patterns related to forager use of fire.

**Domestic cooking installations**

The study of cooking practices had attracted a lot of interest among ethnoarchaeologists because of the exceptional window that ethnography opens to the entire *chaîne opératoire* of one of the most fundamental human activities (David and Kramer 2001). Geo-ethnoarchaeological works used multiple analyses, including soil micromorphology, infrared spectroscopy, stable isotopes, elemental analysis and microscopic analysis of micro-remains (e.g. wood ash pseudomorphs, phytoliths and dung spherulites) in order to associate the domestic use of fire for cooking with microscopic and chemical proxies.

One of the first ethnoarchaeological studies of chemical signatures related to human activity was conducted by Middleton and Price (1996). They analyzed the chemical composition of earth floor sediments from a living house in Mexico in order to build a reference framework for future elemental analysis at archaeological sites. Although their study did not focus on fire residues specifically, they argued that elevated concentrations of P, K and Mg in floors result from deposition of wood ash due to food processing and burning. Middleton and Price (1996) concluded that people’s cleaning practices remove ash and organic matter from the house floor which reduce the concentrations of P, K and Mg within the activity floors but increase their concentrations in waste areas where fire residues are redeposited. The results of Middleton and Price (1996) were repeated by a later study conducted by Rondelli et al. (2014) who studied a domestic unit in rural India. Rondelli et al. (2014) analyzed the chemical composition of earth floors in different activity areas inside a living house including areas used for storage, sleeping, cooking and eating, as well as a cooking fireplace located outdoor in the veranda. They show that areas used for cooking, indoors and outdoors, exhibit elevated concentrations of P, K and Mg due to the deposition of ash. An expansion of this study focused specifically on fireplaces integrating phytolith and elemental analysis with the ethnographic data in order to test the usefulness of these analytical methods to detect combustion features,
fire residues and type of fuel used (Lancelotti, Ruiz-Pérez, and García-Granero 2017). Lancelotti, Ruiz-Pérez, and Garcia-Granero (2017) were able to identify different fuel practices including the use of dung and wood. They demonstrated how the center of the fireplace may present only the last episode of use and concluded that in order to grasp the full extent of fuel use it is essential to consider also samples from the fireplace’s immediate surroundings.

Lancelotti and Madella (2012) worked in rural India focusing on the archaeological markers for the use of animal dung as a fuel material. Animal dung was first mixed with water, shaped into “cakes”, dried and then used as fuel. Working in a living village they were able to follow the production process of the dung cakes and correlate it to the microscopic remains they later analyzed in the laboratory. They carried out a chemical analysis and studied the distribution of phytolith and dung spherulite concentrations of the dung cakes. Lancelotti and Madella (2012) showed that the phytolith content of dung cakes is mostly associated with grass leaf/stem phytoliths (ca. 95%) and very few inflorescences and woody phytoliths. Very few dung spherulites were reported from their dung cake samples. Hence, they argued that that the absence of spherulites could not be taken as an evidence for the absence of dung input. Their elemental analysis of the dung cakes demonstrated that the main factor influencing the chemical composition of their samples was whether the dung was fresh or burnt. As opposed to their fresh mode, burnt dung cakes presented elevated concentrations of Al, Ba, Ca, Co, Cr, Fe, Mn, Mo, Ni, Pb, Sc, Sr, Ti and V. Concentrations of P did not show a significant difference between the fresh and burnt samples.

A study by Gur-Arieh et al. (2013) used a geo-ethnoarchaeological approach for studying the archaeological formation processes of microscopic residues found within cooking installations (see also Portillo et al. 2017). They investigated contemporary cooking practices in rural Uzbekistan where the use of earth-made hearths and ovens was recorded and sampled (Figure 2). They investigated two types of cooking installations, tandir – a cylindrical oven, made of two layers of rammed earth with a large opening at the top and a ventilation hole at the bottom which was either placed vertically on the ground or horizontally on an earth-made platform (Figure 2(a)); and ochock – a partially enclosed hearth (key hole or horseshoe-shaped) built from soil mixed with chaff with two large openings, one at the top on which cooking utensils are balanced and one at the front where fuel is added (Figure 2(b,c)). Gur-Arieh et al. (2013) measured the temperatures within the different types of cooking installations when using different types of fuel, namely dung or wood (Figure 2(a,b)). The pattern recorded showed that in all the installations, regardless of the type of fuel, at first the temperature climbed up as high as 800°C, while after ca. 20 minutes temperatures usually dropped rapidly with the actual cooking temperatures stable at around 350–250°C. Later, they sampled the mud walls of the installations as well as the fuel remains left at the bottom of the installations for further laboratory analysis (Figure 2(c)). Infrared spectroscopy of the earthy wall material revealed that the clay in the inner part of the installations showed alteration associated with exposure to the highest temperature (800°C), much higher than the actual cooking/baking temperature. The exterior walls, on the other hand, showed no signs of clay alteration due to burning. Gur-Arieh et al. (2013) devoted a large part of their research to study the micro-remains of fuel materials, namely wood ash particles, phytoliths (Figure 2(d)) and dung spherulites (Figure 2(e)). They develop methods to distinguish between wood and dung
fuel remains. They sampled each fuel material separately before it was used in the installations as well as the originated ashes after use. They showed that phytolith analysis was not sufficient by itself, as both dung and wood ashes present similar phytolith assemblages due to the local animal diet and mixing of fuels in the installation base. Using pure and mixed samples, they were able to build a model for the identification of fuel type based on phytolith concentration together with the ratio between two indicative markers: (1) the amount of calcitic wood ash pseudomorphs for wood fuel; and (2) calcitic dung spherulites for dung cake fuel. This method significantly improved the ability of geoarchaeologists to identify the type of fuel used in archaeological combustion features, and to assess the relative intensity of fuel used in mixed ashes (e.g. Gur-Arieh et al. 2014; Portillo et al. 2017).

**Burnt houses**

Archaeological fire is mostly associated with human use of fire for cooking, heating and tool making (e.g. ceramic, metallurgy and lime plaster). Nevertheless, many archaeological sites present fire residues due to conflagrations. Friesem et al. (2014a, 2014b) carried out a geo-ethnoarchaeological research of mud-brick houses in rural Greece. Part of this study focused on two adjacent mud structures that were burnt down due to conflagration (Figure 3(a,b)). Informants who owned the structures provided information regarding their use as a stable and a barn. They were also able to supply detailed information about how earth floors were constructed and maintained, the production of mud bricks for the walls and the composition of roofs made of beams covered with branches and
topped by industrial clay tiles. The ethnographic data also included the description of how the fire started in the nearby field and was caught by the roof causing it to collapse on the floor. The structure was then abandoned (about 30 years before the sampling took place) and left to slowly decay as the structure was exposed to the elements. Their field observations noted a darkly burnt horizon measuring a few centimeters in thickness above a sterile substrate and below industrial roof tiles (Figure 3(c)). The lower parts of the inner wall surface showed reddening probably due to burning. Friesem et al. (2014a, 2014b) trenched the structures and sampled sediments from the sterile substrate, the floor and black layer as well as wall material. The sediment samples were analyzed in the laboratory using soil micromorphology, phosphate concentrations, phytolith analysis and infrared spectroscopy. The authors showed that the walls were exposed to higher
temperatures at their lower part when the roof collapsed while still burning, in accordance with the ethnographic information. The most interesting evidence provided by this study was the identification and distinction between two micro-layers that formed the darkly burnt horizon. The upper layer exhibited elevated concentrations of phosphate, phytoliths and wood ash, while the lower part showed more charred remains indicative of lower burning temperatures (Figure 3(d)). Although the two layers presented a similar micro-stratigraphy, the lower part of the burnt layer in the stable contained dung remains and fragments of quicklime spread deposited just on top of a beaten earth floor. Indeed, when the informants were asked about the quicklime spread they detailed the use of lime for periodically cleaning the stable floor. At the adjacent barn, the equivalent lower part of the burnt layer showed charred vegetal remains trampled into the beaten earth floor. The taxonomy of the phytoliths from the upper layer indicated the deposition of plants that were used for roofing while the lower layer showed phytoliths assemblages indicative of fodder. Friesem et al. (2014b) argued that the lower part of the burnt layer represented the activity remains (e.g. dung and lime spread in the stable and fodder in the barn) while the upper part represented the remains of the thatch roof that collapsed on the floor while burning and experienced higher temperatures. Based on the geo-ethnoarchaeological data, Friesem et al. (2014b) introduced the term “floor-roof complex” – referring to a layer of millimeters to a few centimeters thick composed of collapsed roof remains mixed with activity remains from the floor. The authors concluded that only microscopic analysis allows distinguishing roof remains from floor deposits. This observation has significant implications for archaeological studies that often attributed fire residues on floors only to activity remains, while they probably represented both floor and roof remains rather than only primary floor residues. Following this study, geoarchaeological studies were able to successfully identify roof remains in burnt houses from domestic archaeological contexts (e.g. Regev et al. 2015).

**Archaeological implications**

**Human behavior**

Human behavior is reflected by a wide range of practices, but these activities are often subjected to specific constraints that make them identifiable. For example, as demonstrated by this article, there is great variability in the types of fuel (at least in prehistory) and the ability to build a reference framework of the material evidence for such practices is what makes geo-ethnoarchaeology fundamental to inform archaeological interpretation. Geo-ethnoarchaeological studies dealing with chemical and physical signatures were able to contribute general guidelines that have proven invaluable for understanding the archaeological formation of fire residues.

The ethnoarchaeological setting helped geoarchaeologists to associate specific microscopic and chemical markers as indicative to different types of fuel, mainly plants and dung, and to develop new methods to distinguish between them (Lancelotti and Madella 2012; Gur-Arieh et al. 2013; Lancelotti, Ruiz-Pérez, and García-Granero 2017). In addition, the amount of fuel, for example in cooking installations (Gur-Arieh et al. 2013) as opposed to open fires (Mallol et al. 2007; Friesem et al. 2017), was studied in order to understand the correlation between the intensity of use and the deposition of...
fire residues. To date, the main focus in the study of fuels concentrated mainly on wood and dung. Archaeological studies suggested the possibility of other organic materials used as fuel, for example, bones (e.g. Schiegl et al. 2003; Mentzer 2009; Yravedra and Uzquiano 2013; Reidsma et al. 2016) or peat (e.g. Branigan, Edwards, and Merrony 2002; Simpson et al. 2003; Braadbaart, Marinova, and Sarpaki 2016). Geo-ethnoarchaeological studies should be encouraged to broaden the study of other sources of fuel that will increase the ability to trace them in the archaeological record.

Another important contribution of the geo-ethnoarchaeological research is found in the examination of use patterns in association with the deposition of fire residues. Mallol et al. (2007) and Friesem et al. (2017) demonstrated how ephemeral open fires, common among foragers, are expected to leave very scarce remains, but also how microscopic analysis is able to detect “fire proxies” even when macroscopically there is a lack of evidence. Works in domestic households showed that repeated use of cooking installations is more likely to produce a set of fire residues including a chemical signature (Middleton and Price 1996; Rondelli et al. 2014) and higher volumes of fuel remain (Gur-Arieh et al. 2013). In such contexts, it was demonstrated that although the cooking temperatures can be relatively low, microscopic fire residues record the highest temperature, usually associated with the short but repetitive duration of ignition (Gur-Arieh et al. 2013).

Ethnoarchaeological studies highlighted the abundance of routine cleaning practices. In particular, sweeping plays a significant role in the removal of residues from their primary location and their re-deposition in waste areas (e.g. O’Connell 1987; Fisher and Strickland 1989; Milek 2012; Friesem and Lavi 2017). The re-deposition of fire residues due to cleaning practices is crucial because, in the case of open-air sites, the rapid rate of accumulation in waste areas is a key factor for the preservation of activity residues, being in such cases the only marker documenting fire use (Friesem, Zaidner, and Shahack-Gross 2014; Friesem et al. 2017). Unfortunately, the practice of sweeping is still neglected in many archaeological studies probably due to the difficulty to provide direct evidence for its occurrence.

Finally, in abandoned houses, the main factor that seems to control the preservation of occupation residues is the type of abandonment (Cameron and Tomka 1993). Several geo-ethnoarchaeological studies showed that when planned abandonment of houses occurs the preservation of primary microscopic activity remains is poorer, including fire residues, as opposed to sudden abandonment due to destructive events, where often a burnt layer is found in close proximity of the floor (e.g. Goodman-Elgar 2008; Friesem et al. 2011; Milek 2012; Friesem et al. 2014b). However, a geo-ethnoarchaeological study by Friesem et al. (2014b) argued that in many cases this burnt layer might represent the remains of a collapsed burnt roof rather than primary activity residues.

**Taphonomic processes**

In addition to anthropogenic processes, natural processes play a crucial role in the formation and taphonomy of the archaeological record. Geo-ethnoarchaeology has broadened the use of ethnographic contexts also to inform on taphonomic processes by studying recently abandoned settlements. This methodological approach proved highly useful to follow environmental processes occurring post-abandonment and to evaluate their effect on our ability to detect human activities. This near-archaeological setting
can only rarely be constructed experimentally and manifests the importance of ethnoarchaeology for the study of archaeological site formation processes. Geo-ethnoarchaeological studies that examined recently abandoned sites provided models for how different environments and contexts affect the formation and the preservation of archaeological materials (e.g. McIntosh 1974; Shahack-Gross, Marshall, and Weiner 2003; Mallol et al. 2007; Goodman-Elgar 2008; Friesem et al. 2011; Milek 2012; Friesem et al. 2014a, 2014b, 2016).

This approach is especially important when examining the archaeological evidence (or the lack of evidence) accounting for the use of fire. The growing number of geo-ethnoarchaeological studies in different parts of the world help to better evaluate the influence of the environment on the integrity of the archaeological record. Working in a tropical forest, Friesem et al. (2017) showed that in humid tropical environments, high precipitation with intensive biological activity within the soil provides acidic conditions that result in the complete dissolution of carbonates which include wood ash and bone. This study highlighted the importance of studying charcoal, phytolith and certain elements as reliable markers for the use of fire in tropical forests, simply because in acidic conditions they are better preserved than ash and bones. According to the authors, this explains why the majority of archaeological fire residues found in humid tropical environments are reported as charcoal, whereas the few cases where ashes and burnt bones were found correspond exclusively to sites located in a carbonate-rich environment preventing acidic conditions such as karstic systems (see Friesem et al. 2017 for review on fire residues in humid tropical environment). Working in a semi-arid environment, Mallol et al. (2007) showed how ashes are easily transported by the wind and that even with low precipitation ash can dissolve. These two studies (Mallol et al. 2007; Friesem et al. 2017) showed how in open-air sites wind and rain are the major agents in the weathering of fire residues, alongside root and biological activity within the soil. But beyond the environmental conditions, geo-ethnoarchaeological studies focusing on roofed areas or enclosed spaces (Middleton and Price 1996; Mallol et al. 2007; Rondelli et al. 2014; Friesem et al. 2014b), rock-shelters or caves (Friesem et al. 2016; Friesem et al. 2017) and closed installations (Gur-Arieh et al. 2013, 2014) reported much better fire residue preservation states. Thus, the conclusion of these studies is that the preservation of archaeological residues is dependent upon their protection from the elements through rapid burial and/or anthropogenic covers.

The insights provided by the geo-ethnoarchaeological studies allow us to understand why the majority of prehistoric fire residues are found in caves and rock-shelters (Goldberg, Miller, and Mentzer 2017) with only very few rare cases providing evidence for the use of fire in open-air sites (Goren-Inbar et al. 2004; Friesem, Zaidner, and Shahack-Gross 2014). In other words, the geo-ethnoarchaeological works on fire residues clearly indicate that the lack of widespread evidence for the use of fire in open-air sites is due to taphonomic processes rather than to human preferences.

**Conclusions**

Understanding the use of fire is very important to archaeologists as they try to reconstruct past human life. However, understanding how fire residues are formed, preserve or disappear from the archaeological record is often difficult. Geo-ethnoarchaeology uses contemporary contexts to investigate both living and recently abandoned settlements in order to
directly link human behavior with the formation of microscopic and chemical markers and to unravel the post-depositional processes that affect the formation of archaeological evidence. Geo-ethnoarchaeological studies provided several markers associated with fire residues such as altered sediments, wood ash pseudomorphs, phytoliths, charcoal, burnt bones, chemical elements (e.g. P, Mg, K) and deposition patterns. They also highlighted the main agents in the preservation and deterioration of fire residues that are wind, water, bioturbation, soil acidity and human practices such as sweeping and rake-out. Geo-ethnoarchaeology is an emerging approach that has proven to be very useful to understand archaeological site formation processes. Future geo-ethnoarchaeological research, in particular regarding the use of fire, is needed to broaden our understanding of how specific human behaviors result in different formation processes of fire residues, alongside the study of how distinctive environments affect the preservation and archaeological visibility of fire.

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No potential conflict of interest was reported by the author.

Notes on contributor

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