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Anthracology and taphonomy, from wood gathering to charcoal analysis. A review of the taphonomic processes modifying charcoal assemblages, in archaeological contexts

Isabelle Théry-Parisot [a,*], Lucie Chabal [b], Julia Chrzavzez [a]

[a] UNSA, Centre d'étude Préhistoire, Antiquité, Moyen Âge (CEPAM UMR 6130 CNRS), 250, rue Albert Einstein, 06560 Valbonne, France
[b] Université Montpellier 2, Centre de bio-archéologie et d'écologie (CBAE UMR 5059 CNRS), Institut de Botanique, 163 rue A. Broussonet, 34090 Montpellier, France

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ABSTRACT

A discussion on the representativeness of charcoal from archaeological contexts and their potential for palaeoecological reconstruction is presented. The charcoal deposits studied are the result of human activities and natural processes, difficult to separate on the basis of their effects only. This is why "taphonomy" should not be limited to the study of charcoal, after the extinction of fire. As a result our questioning has been widened to include the entire succession of processes, from past vegetation to the anthracological diagram. We propose a review of the taphonomic processes affecting anthracological assemblages in archaeological contexts, from wood gathering to the analysis of charcoal results. Human practices appear clearly as the first filter determining or conditioning the assemblage. The combustion process can induce a double filter by limiting the taxonomic information and by falsifying the initial quantity of burned wood. Post-depositional agents represent a third level of filters between the vegetation and the anthracological assemblage. Finally, sampling and quantification methods can also induce a distortion of the assemblage. The aim of this paper is to present the state of the discipline today, the problems already solved, and the questions that remain to be studied.

1. What is taphonomy?

Among the scientific community, an ongoing debate exists on the definition of taphonomy. This term first used by Efremov (1940), derives from the Greek *Taphos* (tomb) and *Nomos* (law), and literally means "law of burying". According to Efremov (1940), this term refers to all the processes occurring after the death of an organism up until its fossilization. Strictly speaking, this definition, as applied to our research field, would limit taphonomy to the study of charcoal 'evolution', right after the extinction of the fire.

Archaeology has a wider definition of taphonomy, including not only the natural processes which modify the thanatocoenose, but also all the cultural choices and gestures which have an impact on the plant, animal or human materials, from their natural environment to their fossilization.

This use of the word "taphonomy" is not universally agreed upon. But, beyond this problem an important question remains: are taphonomic studies in charcoal analysis strictly limited to post-depositional processes affecting organic materials?

Generally speaking, the charcoal deposits we study are the result of many human activities and natural processes linked to each other, difficult to separate based on their effects.

Our horizons have been widened, covering to the totality of the successive and/or interfering processes between past vegetation and the anthracological diagram.

In this paper, we propose a review of the taphonomic processes modifying charcoal assemblages in archaeological contexts, from wood gathering to charcoal analysis. It is therefore necessary to distinguish charcoal originating from "human activities", the subject of this paper, from "natural assemblages" such as residues from recent and ancient wildfires, only sporadically referred to.

2. A broad definition of taphonomy: from wood gathering to charcoal analysis

The nature of the processes involved is diverse (Fig. 1): (1) human practices with wood collecting and hearth management, (2) combustion itself and (3) depositional and post-depositional processes. According to some authors, only these last processes should be included in the definition of "taphonomy". Furthermore, we also believe that "archaeologist" and "anthracologist" filters should also be considered as sampling and quantification methods, may also distort the final assemblage. All of these filters (or agents) must be taken into account when considering distortional factors between the natural environment and the charcoal diagram. Conditions are different in natural contexts since the first filter (i.e. human practices) is excluded.

In archaeology, this definition of taphonomy has to include the human filter. When our study focus on the woody vegetation and its

* Corresponding author.
E-mail address: thery@cepam.cnrs.fr (I. Théry-Parisot).

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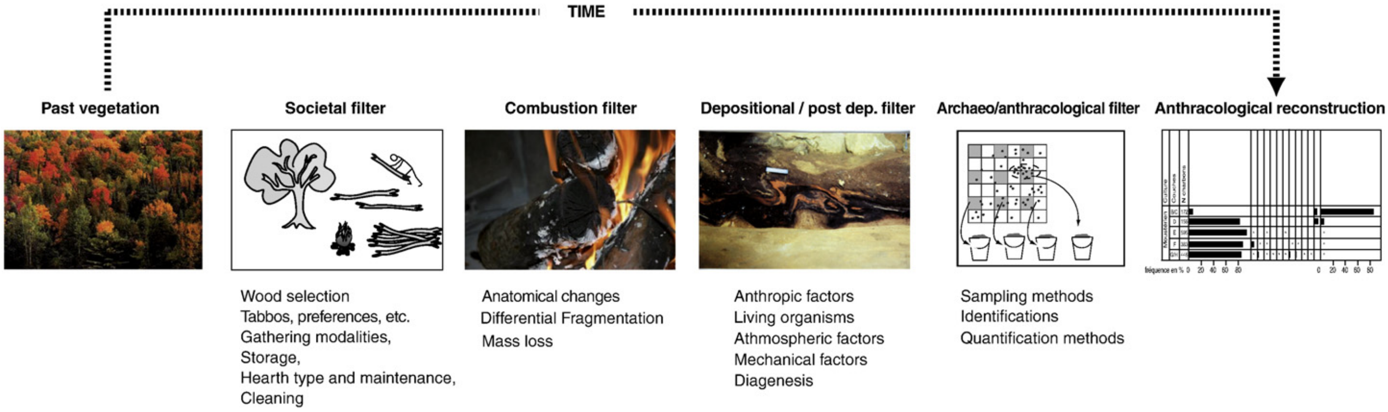

Fig. 1. Successive filters from the past vegetation to the anthracological reconstruction.

evolution, it is obvious that its perception based on the wood collected is dependent on human practices. Therefore, societal factors cannot be ignored when estimating how representative of the surrounding vegetation our charcoal assemblages are. On the other hand, when our research concerns anthropogenic practices alone, these can be studied for themselves and not as a potential bias affecting the representativeness of the assemblage. Thus, the question is less one of terminology, than one of clear formulation of the research goals of each charcoal study, which will allow us to attribute, or not, a taphonomic value to the different filters. It is clear, however, that charcoals are often considered in both perspectives: economical (or technical) and environmental.

3. Charcoal analysis and taphonomy: a recent history

Taphonomic studies of charcoal are fairly recent in archaeological contexts. What are the reasons for this slow evolution of the discipline in archaeological contexts?

Charcoal analysis began in the 40s (Salysbury and Jane, 1940; Godwin and Tansley, 1941; Balout, 1952; Santa, 1961; Couvert, 1968; Couvert, 1969a,b), and developed when reflected light microscopy allowed the systematic and rapid identification of charcoals (Western et al., 1963; Stieber, 1967, 1969; Western, 1971; Vernet, 1972, 1973; Leney and Casteel, 1975). By the beginning of the 80s, archaeo-anthracological studies were already relatively frequent, but the discipline still suffered from a relative lack of methodological background. It is in this context that the first systematic research was carried out at Montpellier, under the supervision of J.-L. Vernet (Thiébault, 1980; Chabal, 1982, 1988, 1990, 1992, 1994, 1997, 1991; Heinz, 1990; Heinz et al., 1992; Badal-Garcia, 1992; Figueiral, 1992; Grau Almero, 1992; Vernet, 1992; Fabre, 1996; Théry-Parisot, 2001, 1998; Figueiral and Willcox, 1999; Thiébault, 2002). The first methodological approach in support of the palaeoecological representativeness of charcoal assemblages and the quantification methods used was carried out by Chabal (1997). Today, thanks to these studies, charcoal analysis has at its disposal a strong methodological and analytical framework. According to Chabal (1997) the palaeoecological representativeness of charcoal from archaeological contexts depends on three conditions:

(1) Charcoal samples should originate from domestic fuel wood (even if sporadic non-domestic activities may also provide similar reliable data (e.g. Chabal, 2001))
(2) Charcoal must correspond to long-term activities, representative of the environment, i.e. scattered charcoal in archaeological layers. Specific deposits, like fireplaces, can provide interesting information but are rarely representative of the whole environment. It is therefore fundamental to distinguish two types of charcoal deposits:
   - Heterogeneous deposits in relation to a specific activity (e.g. charcoal from fireplaces, kilns or other structures), easily identifiable, for which an intentional selection cannot be distinguished from random sampling;
   - "Synthetic" deposits i.e. scattered charcoal in the archaeological layer, resulting from long-term deposition and mixing, difficult to link precisely to specific activities, but with a reliable significance concerning the environment.

It is important to notice that the filling of hearths or kilns, can sporadically function as a "synthetic" deposit, when these structures were used frequently without cleaning. The factor 'length of time' is not necessarily related with the number of charcoal pieces recovered from these structures and their contents must be analysed carefully. (3) Concerning "synthetic deposits" a minimum of 250 to 400 charcoal specimens (> 4 or 2 mm depending on the period) has to be sampled from each archaeological layer, excavated according to specific digging methods (e.g. Damblon et al., 1996; Damblon and Haesaerts, 2002) and obtained by sieving of the sediments. When these conditions are fulfilled, the representativeness of the charcoal assemblage depends on three arguments:

(1) The observation (list and frequencies of species) is reproducible in the layers of the same period throughout the site (this observation is based on the spatial analysis of charcoal) even if charcoal samples belong to different areas, such as dwellings, dumping fills, etc. If one sample, for unknown reasons, doesn't fit this condition, it must be excluded from the study.
(2) The samples are rich in taxa, both in briefly occupied settlements or in long-term sedentary occupations; depending on the physical environment, 30 to 40 taxa may be identified in a long-term occupation. Nevertheless, the charcoals sampled in Pleistocene occupations might not present a high taxonomic variability due to the low specific diversity of woodlands at that time.
(3) The list and frequencies of species are in accordance with modern ecology (dominant or subordinate species), the anthracological diagram is coherent with other diagrams, in space and time, and significant in terms of woodland dynamics, even if not exactly similar to the present.

The strength of this argumentation resides in the fact that it is supported by data from multiple archaeological sites and comparison of results. Data already obtained cannot be thrown into doubt. Provided that the assemblage identified is considered representative, no questions concerning human choice or strategy, combustion processes, or post-depositional processes need to be raised.

These last questions can be further considered. Once the conditions of palaeoecological representativeness were exposed and accepted by the scientific community, it was possible to evaluate the role of human behaviour as a taphonomic agent.

4. The societal filter

When questioning the biases affecting the representativeness of the charcoal assemblage, man appears clearly as the first filter. His choices, his preferences and his actions determine or condition the assemblage. Indeed, the question of specific wood selection as a bias of the assemblage appears as a justified debate. However, arguments used are almost always the result of a direct transfer from our subjective vision of human practices towards archaeological situations. In general, no precise link is established between the real practices and the fact that a charcoal assemblage can or cannot be representative of the vegetation.

Obviously, society organisation differs profoundly across time, from hunter–gatherers to sedentary and technically developed populations. But the precise way of collecting wood, and the way of managing woodlands in each period, is not our subject of discussion. Many analytical questions can be considered beforehand. They are tools for understanding each particular situation of the past, avoiding generally accepted ideas. Nevertheless we will give concrete examples throughout our reasoning.

The question of the societal factor can be apprehended according to three approaches: an inductive, an experimental and an ethno-anthracological approach.

4.1. The Inductive approach

4.1.1. Gathering and the Principle of least effort

The question of human practices and their incidence on the assemblage was debated since the first charcoal studies with Salysbury and Jane (1940) and Godwin and Tansley (1941). The Principle of Least Effort (Prior and Price-Williams, 1985; Chabal, 1991; Shackelton and Prins, 1992) has greatly influenced charcoal interpretation. According to this paradigm, firewood gathering took place in a reduced area and all the species were indistinctly collected in proportions similar to those of their occurrence in the environment. At this point, the question about the duration of charcoal accumulation becomes crucial. According to Chabal (1997), there is a threshold after which the successive accumulations of collected wood represent the majority or all of the fuel wood provided by the surrounding area. Inversely, it has been demonstrated that a sporadic deposit provides an instantaneous picture of the environment that remains difficult to distinguish from a selective choice of wood (Chabal, 1982, 1991; Badal-Garcia, 1992; Chabal, 1997). As already referred to, the distinction between a short-term and a long-term activity is based mainly on the concentrated or scattered character of the charcoal (and not necessarily on the number of charcoal pieces of the deposit).

4.1.2. About the notion of species

The notion of species is a quite recent concept: the Linnaean classification refers to botanical criteria without relation with the use of the wood. This classification cannot be transferred to the one of former societies (Levi-Strauss, 1962). According to this ethnologist, there are countless examples showing the existence of a single nomenclature for a group of botanically distinct species because of their similar properties or uses. For example, on the northern coast of Alaska, the local population uses the expression "kun.na.ta.kin" when referring to all the species used for firewood, indiscriminately (Alix, 1998, according to Petersen, 1986). Conversely, Inuit populations from Greenland give different names to drift wood according to its quality and its use, without considering the botanical species (Alix, 1998; Alix and Brewster, 2005). Transposing our notion of "species" to past situations does not consider that native classifications probably reflect a perception of the environment, which is not ours (Théry-Parisot, 1998, 2001, 2002, Henry and Théry-Parisot, 2009).

4.1.3. The question of the "best fuel"

It seems reasonable to correlate the choice of plant species with their combustible properties. But the notion of a good fuel is a very recent principle which refers to domestic heating wood. Our limited use of fire tends to restrict our idea of "good fuel" to a few criteria such as easy ignition and durability to the detriment of all other combustion properties. Today, as well as in the past, there is not one good fuel but a wide choice of adaptable good fuels for diverse activities (Chabal, 1997; Bourquin-Mignot et al., 1999; Théry-Parisot, 2001, 2002). The way in which heat transfers during combustion will influence the choice of the most adapted wood for each activity (Fig. 2). It is therefore difficult to argue in favour of the selection of species when taking into account only the recent notion of "good fuel".

4.1.4. The wood fire properties

The combustible properties of wood are more complex than one usually admits. They certainly depend on the species: according to its density or its chemical composition the properties of wood vary from one species to another. But most of all, as demonstrated by several studies, combustible properties depend on the calibre, the rate of humidity and/or the physiological state of the wood (healthy wood *v.* dead-decayed wood) (Trabaud, 1976, 1989; Briane and Doat, 1985; for a detailed bibliography see Théry-Parisot, 2001, pp.151–159). For example, the calorific value varies little from one species to another (from 4000 to 4500 kcal/kg, Théry-Parisot, 2001, fig. 46, p. 157), but fluctuates significantly according to the water content (Fig. 3). To start the fire, the calibre of wood used, i.e. small branches or split wood is more important than the species itself. Consequently, to define the combustible properties of the species chosen and the reasons why they were chosen (i.e. heating, drying, cooking, etc.) we have to identify not only the species but also those three fundamental parameters: calibre, rate of humidity and physiological state. These, however, are seldom identifiable. As demonstrated by ethnology, the wood's phenological and physiological states, its calibre and/or availability, could have determined selection strategies, which cannot be demonstrated on the basis of archaeological observations alone (Nicholson, 1981; Smart and Hoffman, 1988; Alix, 1998; Alix and Brewster, 2005; Henry and Théry-Parisot 2009; Joly et al., 2009).

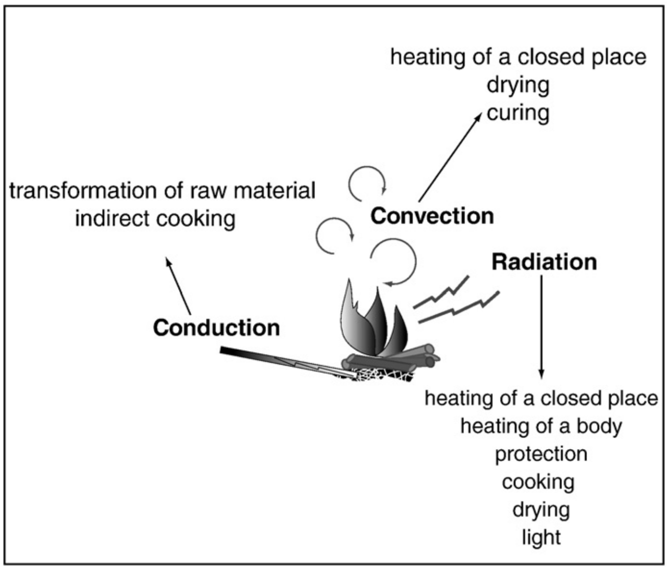

Fig. 2. Hearth functions and heat transfer.

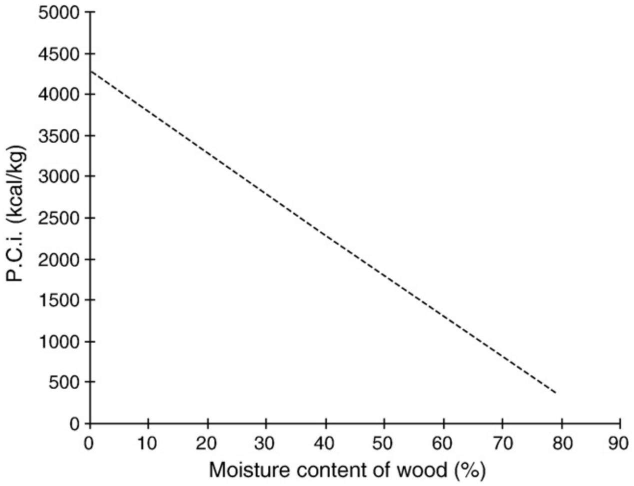

Fig. 3. Interaction between moisture content of wood and its calorific power.

Thus, the choice of species for firewood appears more as a possibility than a necessity. Our purpose is not to deny the existence of choices, but to show that they can be the answer to many possible logical choices, in which the availability of each kind of wood remains a constant constraint. For example, cutting and storing the wood are highly constraining for nomadic populations. Dead or drift wood, already dry, easier to gather, might have constituted most of the firewood supply of these populations. For other populations, other criteria could have been also taken into account, e.g. objective criteria of wood combustibility (according to species, calibre or physiological and phenological states), subjective criteria linked to cultural contingencies, simple preferences or taboos. The societal filter is therefore a reality difficult to perceive. It is obvious that, it will always be difficult to distinguish patterns of over-or under-representation of taxa.

But, in many cases, we can assume that the reasons behind the choices didn't vary and that the distortions of anthracological spectra are constant through time and don't hide real environmental variations. Palaeoecological interpretations can therefore be put forward.

4.2. Anatomic signatures and human practices: the experimental approach

As previously explained, the taxonomic identification of archaeological wood, does not allow us to go very far in the interpretation of human practices. Wood gathering, e.g. collecting dead wood or cutting fresh wood and then storing it, does not always have the same consequences on the composition and the representativeness of the charcoal assemblage.

Considering the representativeness of charcoal assemblages from archaeological sites, we can consider another possible filter of natural origin. For example, the natural transport of dead trees could lead to the accumulation of drift wood on the river banks, easily collected by man. In this case, the riverine species will be over-represented in charcoal. Another possible "natural filter" concerns species which decay faster thus disturbing the wood assemblage used as fuel. This type of biases can sometimes be analysed.

Moreover, different authors have developed ways of characterizing the gathering/cutting practices via the recognition of wood anatomical signatures. Their work relies on the experimental reproduction of modern analogues. Marguerie and Hunot (2007) have presented a first synthesis of studies carried out on dendrology, growth-ring measurements, cracks, vitrification or bacteriological attacks (Ludemann and Nelle, 1992; Marguerie, 1992; Théry et al., 1995; Théry-Parisot, 1998, 2001; Alix, 2001; Alix and Brewster, 2005; Allué et al., 2005; Dufraisse, 2005; Théry-Parisot and Texier, 2006; Enache and Cumming, 2006; Ludemann, 2008). Under specific conditions (sporadic or well dated deposits), these features may testify to the use of dead, dry, green or drift wood. However, the superposition of archaeological deposits from successive short-term occupations, fireplace superposition or cleaning and the mixture of charcoal in the same level, tend to interfere with our interpretation. What we regard as the result of one practice is frequently an average representation of multiple practices. As explained below, it is fundamental to distinguish heterogeneous deposits, in relation to a specific activity, from "synthetic" deposits, resulting from mixing and long-term occupations (i.e. scattered charcoal in the archaeological layer). Scattered charcoal is of high interest for palaeoecological reconstructions but their interpretation is limited when linking the anatomical signatures with a specific activity or a "chaîne opératoire".

4.3. The ethno-anthracological approach

More recently, the development of ethno-anthracological studies have provided information on fuel management, in a more realistic and nuanced way (Solari, 1992; Ntinou, 2002; Moutarde, 2006; Dufraisse et al., 2007; Henry and Théry-Parisot, 2009; Joly et al., 2009).

Without directly transferring present day conditions to the past, the goal of these works is to focus on the diversity of practices and the complexity of real situations. They also test our theoretical models (pertinence and interrelation of parameters) under «real» conditions in which all the parameters are observable, and document the validity of the charcoal deposit in nomad or sedentary contexts.

The work by A. Henry, in Siberia, is a good example of this trend. It shows that a charcoal assemblage resulting from short-term occupations can contain more diversified remains than those from longer occupations (Henry and Théry-Parisot, 2009). Also, mono-specific assemblages may be found in long occupations. Seasonality of occupation, technological contexts, wood cutting or re-cutting, wood picking or storage, are parameters which may interfere, in a specific way, with the composition of the charcoal assemblages. Therefore, it seems legitimate to try to understand the existence of these practices in archaeological contexts.

The main contribution of the ethno-anthracological approach is to show the complexity of fuel wood management systems and thwart us from 'modern' or simplistic interpretations.

4.4. The cultural context

This field of charcoal analysis remains very delicate as it is important to place the societal filter in a well-defined cultural context, for each archaeological site, but difficult to generalize about selection strategies or fuel wood management.

Adopting a systemic approach allows us to take this difficulty into account and to apprehend the question of fuel wood management, in all its complexity. Fire wood management is a complex system resulting from interactions between factors schematically defined as "societal" or "natural" (Fig. 4). Site function and status, material culture, degree of technology, handcraft, fireplace function are as many anthropogenic factors interacting, at every level, with the natural factors such as climate, fuel availability, topography, etc. (Théry-Parisot, 2001; Asouti and Austin, 2005; Théry-Parisot et al., 2009). It seems vain to establish a general model that could be applied to all sites and chronological periods; each site presents its own specificity and each group its own identity. Without considering a dichotomous conception of natural or societal determinisms, which would favour one or the other, we are tempted to think that more than the environmental context, the sedentary life-style probably had the greatest impact on fuel management. A more systematic fire wood management was needed to answer the growing demography, the development of technologies, the increasing energetic needs and, more recently, the juridical factors.

However, all these factors do not prevent a good perception of the woodlands. For instance, archaeological observations in the site of

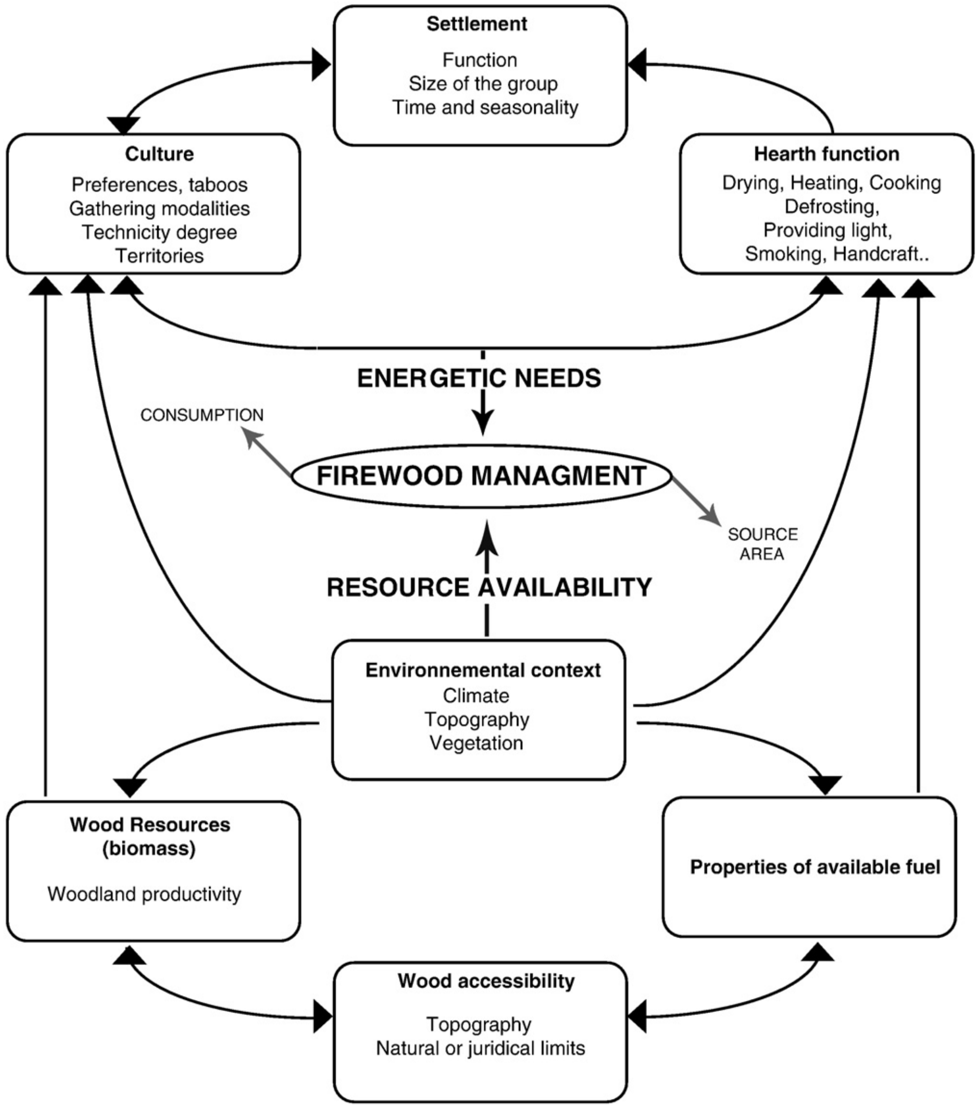

Fig. 4. Firewood management, interactions between natural and societal factors.

Lattara (Hérault, southern France), show that even in urban Iron Age sites the same wood species were used for different needs (ex: domestic hearths, domestic kilns, as building material); the hierarchy of dominant species was kept from one context to the other; the only minor differences noticed concern wood calibre (Jorda et al., 2008). The organisation of the city is unknown to us, but the wood was probably exploited in a restricted area, and the technical necessities found answers independent of the species. It seems that in most of the sites studied the economical and the ecological constraints were harmonized in a reasoned use of the available resources.

5. The combustion filter

The combustion process is a second level of filter that can lead to notable modifications of the archaeological record. Morphological, chemical and physical properties of chard vary upon two main variables that are (1) heat source related variables and (2) wood property variables (Braadbaart and Poole, 2008). As a result, Braadbaart and Poole propose a terminological distinction between the terms "carbonization" and "charring". According to these authors, "carbonization" corresponds to wood burned without oxygen, the residues are charcoal, while "charring" occurs in a limited supply of air. The charring leads either to the formation of charcoal, when combustion is incomplete, or ash, when combustion is complete. Both processes correspond to "charcoalification".

The combustion process can induce a double filter, first by limiting the taxonomical information, and secondly by falsifying the real quantity of initially burned wood and therefore the representativeness of the assemblages.

5.1. The taxonomical information

Logically, the first studies on the taphonomy of combustion focused on the anatomical modifications of wood and their consequences on charcoal identification (Metcalfe and Chalk, 1950; Jane, 1956; Mac Ginnes et al., 1971; Beall et al., 1974; Moore et al., 1974; Schweingrüber, 1978; Zicherman, 1981; Prior and Alvin, 1983; Rossen and Olson, 1985; Thinon, 1992; Prior and Gasson, 1993; McParland et al., 2007). It is important to notice that the charcoalification process has a great importance in preserving the anatomy of the wood even on fossil charcoal (Figueiral and Mosbrugger, 2000; Scott, 2000; Scott et al., 2000; Hockaday et al., 2007). These studies showed that combustion creates some anatomical modifications in the structure such as retraction, fusion or cracks. In spite of these deformations, the global anatomical structure of wood, as well as most of its microstructural elements, remain largely unaffected. Nevertheless, by 1200 °C, charcoal produced under poor oxygen conditions is no longer recognizable (Braadbaart and Poole, 2008).

5.2. The quantity of initially burned wood

It is generally accepted that before characterizing vegetation, the ratio between species, in a charcoal sample, represents the initial proportions of wood used to feed the fire. But how can charcoal reflect human practices while still keeping its palaeoecological significance? Charcoal quantification then relies on the postulate that all the species have an average similar behaviour concerning fire. In reality, when burning, wood suffers both mass loss and charcoal fragmentation. But the effect of these simultaneous processes must be studied independently (Chabal, 1992).

Chabal (1990) demonstrated that the fragmentation of charcoal in an archaeological sample is the same for all species. Comparison of results can thus be achieved by counting of charcoal fragments. However, we only observe a final state, which includes both the combustion and the post-depositional processes (*cf. infra*). This validation applies only to the quantification unit in anthracology, not to fragmentation due to combustion only.

Nevertheless, the question asked is not about the final fragmentation, but about mass loss, for each species, during combustion. Many studies intended for industry deal either with the transformation of wood into charcoal or with chemical characterization. These studies, as well as those focusing on species combustibility, document the functioning of the fire in both societal and natural context, but reveal little on the effects of combustion on fragmentation and mass loss (reduction mass) processes (Mac Ginnes et al., 1971; Beall et al., 1974; Juneja, 1975; Slocum et al., 1978; Cutter et al., 1980; Baileys and Blankenhorn, 1982; Briane and Doat, 1985; Trabaud, 1989; Janse et al., 1998; Lingens et al., 2005).

Thus, some questions on the combustion process are still subject to debate: do species have a differential mass loss and fragmentation during combustion? Are some species under or over-represented? Are the proportions of charcoal from each species strictly correlated to the initial proportions of species in the fireplace? Further questions, concerning our methods include: what fragment size represents best the initial quantity of charcoal for each species? Which unit of measure, weighing or counting, represents best the wood proportions burned?

Since the 70' and 80', experiments, aiming to understand fragmentation and mass loss processes, have been undertaken. However, results vary according to different authors. Some authors establish correlations between wood anatomy and fragmentation. According to Rossen and Olson (1985) dense woods produce more charcoal than soft woods; however, according to Loreau (1994) the opposite happens. According to Scott (1989) the presence of growth rings favours fragmentation. According to this author, high humidity rate sensibly reduces residue rate, which is in opposition with the results we have obtained (Théry-Parisot, Chabal and Ntinou, in process). According to Smart and Hoffman (1988) it is mainly the calibre and the wood arrangement in the hearth that determines the residue rate. Lingens et al. (2005) suggest that the differences in residue rates are linked more to the chemical composition of wood than to its density. In the same way, a correlation between high temperatures and low residue rates is often established. The observation of charcoal issued from potter kilns shows that fragments are sometimes well preserved even under high temperatures. According to Scott and Jones (1991) and Belcher et al. (2005), fragmentation does also depend on temperature of burning and oxygenation. For Vaughan and Nichols (1995), the temperature reached during pyrolysis results in charcoal with different particle size, density, structure and morphology.

Our work, based on 110 experiments carried out under standardised conditions and the study of 298,000 charcoal fragments, clearly shows the complexity of the combustion process. First, we have noticed that the residue rate doesn't depend on the burned volume of wood (Fig. 5). It has also been observed (Analysis of variance between groups) that the humidity of wood before combustion (dry or green) has apparently no impact on the fragmentation process (Fig. 6). An intra-specific and inter-specific behaviour towards fire does exist, but the differences in the residue rate between species are not explained neither by the wood density (Fig. 7), or the combustion duration (Fig. 8), nor by the temperature of combustion (Fig. 9) (Théry-Parisot, Chabal and Ntinou, in process).

This enumeration is not exhaustive, but the diversity of the results obtained, from one author to the other, underlines the fact that the experimental conditions actually determine the effects on those residues. The difficulty to obtain intelligible results, even under standardised conditions, shows that the taphonomic consequences of wood combustion are really difficult to estimate. Furthermore, how is it possible to understand real archaeological conditions when interactions between extrinsic and intrinsic factors, gestures and fire maintenance complicate even more the combustion process? We arrive here at the limits of the experimental approach. Experiments, supposed to mimic taphonomic processes, must necessarily include practices and gestures. In fact an experimental combustion implies choices on the type and duration of lightening, fire reload, ash emptying, etc. Even if we standardize experiments by limiting the variables taken into account, we will necessarily influence the results through our way of operating.

In the end, this non-linearity of species behaviour towards fire is probably a positive result, because it suggests that combustion is a taphonomic agent, which randomly affects deposits; its effect on the assemblage is almost impossible to control. The sum of all combustion biases affecting a plant species, during successive fires, tends to minimise frequency distortions in the sample recovered during field work; the societal filter remains then, the main factor of potential distortion (in relation to past vegetation).

It might be interesting to recall that, during surveys on palaeo-wildfires, modern *in situ* wildfire remains have been studied (e.g. Scott, 2001), under a taphonomic perspective. The mass of fuel and the combustion processes intervening are certainly different from those occurring in the archaeological context; however the results obtained globally attest of the good representativeness of those assemblages (Thinon, 1992; Blackford, 2000; Ohlson and Tryterud, 2000; Scott et al., 2000; Gardner and Whitlock, 2001; Lynch et al., 2004; Enache and Cumming, 2006).

6. The filter of depositional and post-depositional processes

In addition to societal factors and combustion processes, post-depositional agents represent a third level of filters between the vegetation and the charcoal assemblage. They are generated by several types of synchronic or successive phenomena: first of all, the anthropogenic agent will affect the charcoal deposits by trampling, re-

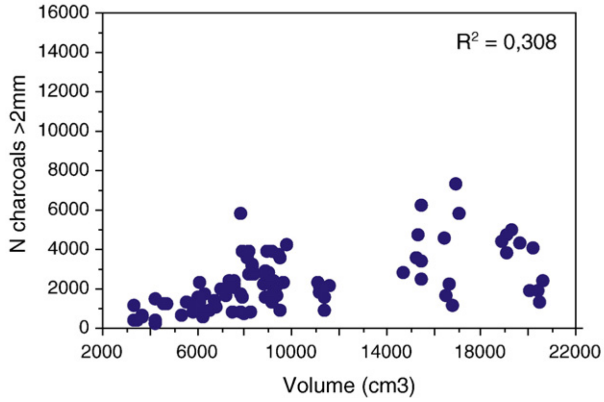

Fig. 5. Volume of burned wood/number of residual charcoal pieces.

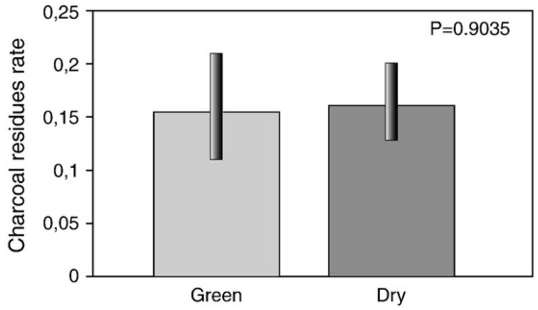

Fig. 6. Moisture content of wood versus charcoal residues rate.

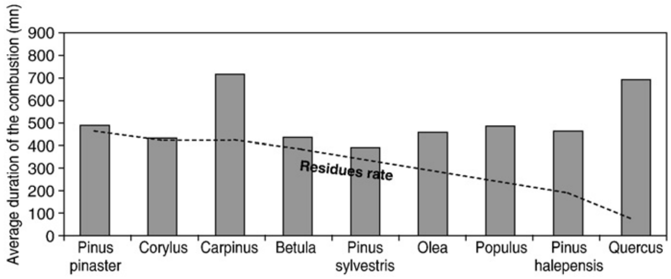

Fig. 8. Average combustion duration versus charcoal residues rate.

workings, sweeping, and cleaning; secondly, living organisms induce bio-pedoturbations; atmospheric factors (runoff, wind action) lead to colluvioning or leaching; mechanical constraints like pressure in the sediment (freeze/thaw cycles or dry/humidity cycles), the rate of burial and diagenesis, induce chemical alterations.

These phenomena can lead to vertical and horizontal migrations which affect the spatial dimension and result in "inversion" of the artifacts in archaeological levels. It can also lead to the fragmentation, or even disappearance of the material, affecting our perception of the wood used as a fuel; this, in turn, can lead us to over-interpret the absence or scarcity of charcoal in archaeological contexts.

The interaction between all these processes can disturb the whole charcoal deposit (all the charcoal independently of the species). But, the question, which logically arises, focuses on the differential conservation of the charcoal depending on the physical and mechanical properties of each species.

6.1. Post-depositional processes: a global agent of alteration?

The effects of the root system and the pedofauna on wood charcoal, as well as the atmospheric or water transport, have been studied by pedo-anthracologists and sedimentologists (Darwin, 1882 — French translation of Darwin, 1881; Stein, 1983; Thinon, 1992; Carcaillet and Talon, 1996; Carcaillet and Vernet, 2001; Carcaillet, 2007).

According to Wood and Johnson (1978), worms can shift archaeological features by nearly 5 mm per year. However, according to Stein (1983), only small charcoal particles, i.e. below 2 mm, can be affected by these processes. Other authors think that archaeological artifacts of more than 2 mm are concerned (P.-J. Texier, P. Bertran, oral comm.).

Burrowing animals, in archaeological sites, present the same risk but their activity is generally noticed during the excavation and the material coming from disrupted areas can be isolated.

The root system of plants can also have a high incidence in natural sequences or in some open-air sites, but are probably less important in rock shelters or cave sites where vegetation is less developed.

According to Clark (1988), atmospheric transport affects very fine particles (few hundred microns) especially the particles below 60 microns, as in the case of vertical migrations due to water circulation. According to Carcaillet and Talon (1996), water can cause horizontal disturbances when the soil is composed of big sized particles (e.g. sand, gravels). Its effect is less important when soils are clayey or silty. Water circulation can move charcoal along great distances, as attested in marine sequences (Thinon, 1992; Vaughan and Nichols, 1995; Blackford, 2000; Nichols et al., 2000; Scott et al., 2000; Berger and Thiébault, 2002). However, these studies mainly concern wildfire residues. We know very little about possible degradation of charcoal by diagenesis processes. Research carried out in the Weizmann Institute has compared archaeological and modern charcoal (Cohen-Ofri et al., 2006). The results show that charcoal alterations could be accentuated in basic soil conditions. The authors suggest that the dark levels, often encountered in prehistoric sites, could originate from wood charcoal degradation in a neutral to basic pH environment. In Kebara Cave (Israel), charcoal is better preserved in acidic contexts than in those with calcite and carbonated apatite (Schiegl et al. 1996). A recent study from Braadbaart et al. (2009) also demonstrates the incidence of alkaline soil on charcoalified plant material: "the deficit of recognizable charcoalified plant material in permeable alkaline soil environments can be attributed predominantly to the physical processes caused by chemical changes affecting the macromolecular structure with chemical post-depositional processes only playing a minor role" (Braadbaart et al., 2009, p. 1618).

The effects of post-depositional processes on all the charcoal remains have to be taken into account. Often, major disturbances also affect archaeological artifacts and can be identified during the excavation or by micromorphological studies. When sites are not affected by ploughing or modern constructions, the stratigraphy of Protohistoric and Roman settlements can be less disturbed than the one of Prehistoric sites. Generally, the diversity of contextual analyses allows us to integrate the post-depositional processes into our interpretation, particularly in the earlier settlements, where the stratigraphy can be difficult to understand.

However, when post-depositional processes homogeneously affect the charcoal deposits inside each layer, they do not affect the palaeoecological signature. The hypothesis that post-depositional processes especially affect some species must still be considered.

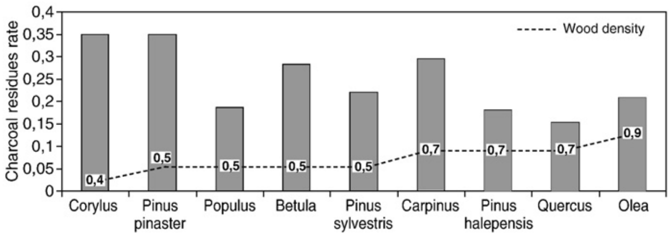

Fig. 7. Wood density versus charcoal residues rate.

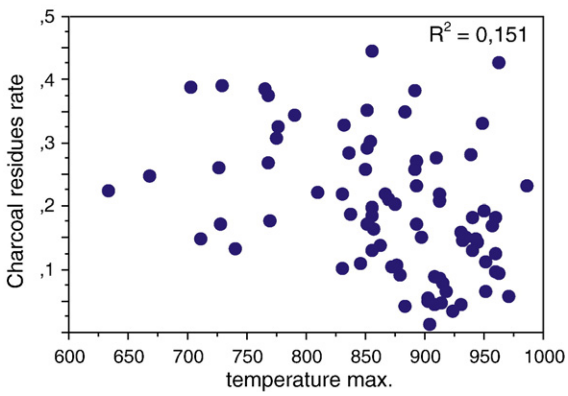

Fig. 9. Maximal temperatures versus charcoal residues rate.

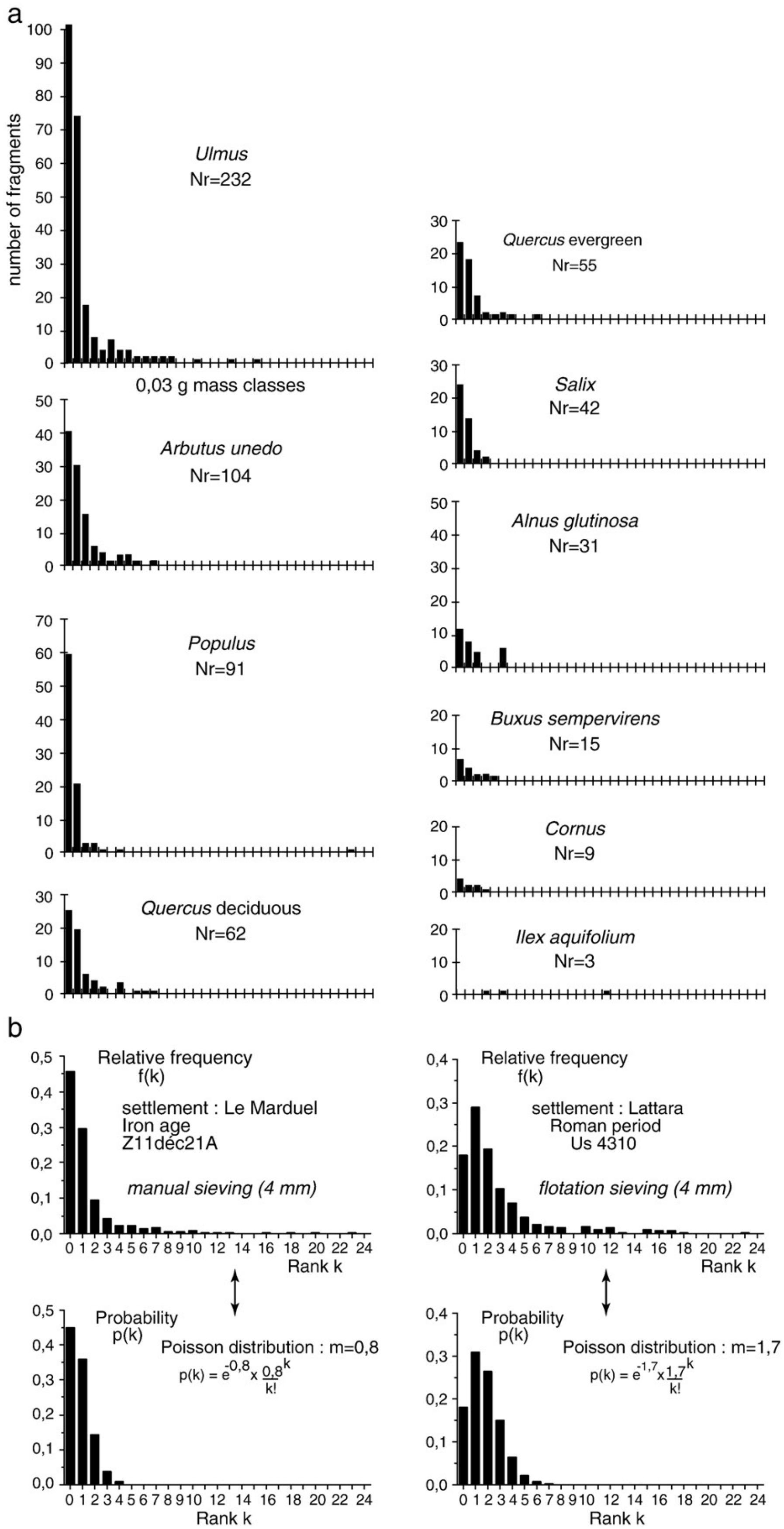

Fig. 10. Histogram of charcoal fragmentation: the breakdown of charcoal during combustion, post-depositional processes and sieving, lead to a statistical process which is very close to a Poisson distribution. (a) Fragmentation is identical for all the species of an archaeological sample; the 'fragment' has the same statistical value for each species. (b) For the same mesh (4 mm), the sieving method (flotation vs manual) modifies the parameters of the Poisson distribution, equally for all taxa.

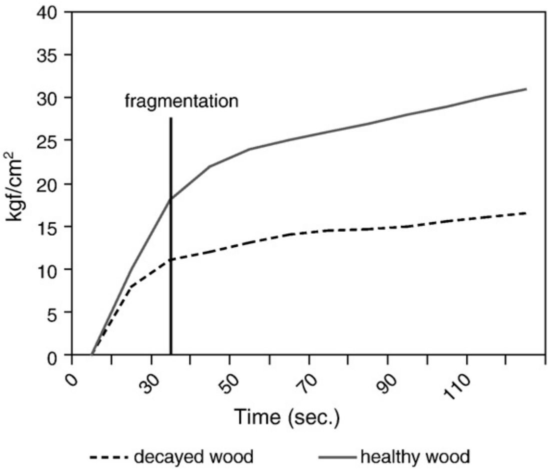

Fig. 11. Mechanical resistance of decayed and healthy wood charcoal (*Pinus sylvestris*). Mechanical tests on charcoal from decayed and healthy wood show that decayed carbonized wood is 3 to 5 times less resistant than healthy carbonized wood.

6.2. A differential preservation of charcoal?

Charcoal differs from the original organic matter in its chemical, molecular and physical properties; this difference is a direct result of the heating conditions i.e. temperature and length of exposure to the heat source (Braadbaart et al., 2009).

The question of the differential fragmentation of charcoal according to their mechanical, chemical and physical properties has been studied based on the post-depositional state of fragmentation (Fig. 10). A statistical study on archaeological charcoal from le Marduel and *Lattara* (France) demonstrates that all the species have a similar histogram of fragmentation (Chabal, 1990, 1992, 1997). Consequently that indicates that all plant species have similar average mechanical and physical properties when transformed into charcoal. These properties, which are different from one species to the other, in wood, may be erased or minimized by combustion. In all probability, the post-depositional processes added to the combustion, could act as a homogenization agent leading to an average similar behaviour of species.

The effect of mechanical processes on the charcoal record has also been analysed, regardless of species properties, and based on the phenological and physiological state of wood before carbonizing (Théry-Parisot, 2001). Mechanical tests undertaken on modern carbonized material (*Pinus sylvestris*), carbonized under standardised conditions, show that the state of the wood before combustion has an important influence on the mechanical properties of charcoal. Healthy carbonized wood is 3 to 5 times more resistant than decayed carbonized wood (Fig. 11). In the same study, experimental simulations of freeze–thaw processes have shown that the gelifract's morphology varies mostly according to the physiological state of the wood before combustion (Fig. 12). Charcoal originating from the combustion of decayed wood, more porous, fragments more, in smaller-sized particles and faster, whereas the combustion of healthy wood produces charcoal dust with preservation of the initial core.

These results show that charcoal is an organic material, whose complex mechanical properties depend on parameters such as species, wood density and porosity, humidity rate, temperature of combustion, etc. As a result the strict definition of species properties, necessary to understand the charcoal record, is difficult to establish. Nevertheless, it seems that species properties are less important than the healthy/decayed state of wood before its combustion. These results clearly show the interweaving of the societal filter with other taphonomic agents. The collecting of dead wood, if decayed, may have a direct impact on charcoal preservation. This can partially explain the scarcity of charcoal in some Palaeolithic sites in which short time occupation probably lead people to favour wood gathering of potentially decayed wood to wood cutting (Théry-Parisot and Texier, 2006). We believe that the absence or scarcity of charcoal can provide information on human practices.

Beyond the simple fragmentation or dispersion of the material, the studies undertaken, both in natural contexts and in archaeological sites, clearly ask the question of the disappearance of material (Thiébault, 1980; Courty et al., 1989; Théry-Parisot, 1998, 2001; Berger and Thiébault, 2002). This phenomenon could be explained by the ongoing hyper-fragmentation, up to the near complete destruction of the material, which seems to be the case in many early sites, in which the hearth structures are «empty». The disappearance of the coarse fraction leads sometimes to the misinterpretation of charcoal absence and to the suggestion, that other fuels, such as bones or dung, were used. Further investigations relying on the study of very thin coarse fractions, are needed, so that more reliable interpretations can be proposed.

7. Conclusion

We have considered, from an analytic point of view, the successive filters which transform the information from the past vegetation to the anthracological reconstruction.

It is important to notice that the whole process results from the non-linear interaction of a great number of factors (Fig. 13): societal factors (wood collecting modalities, energetic needs, types of structures, hearth maintenance, handcrafts, etc), settlement factors

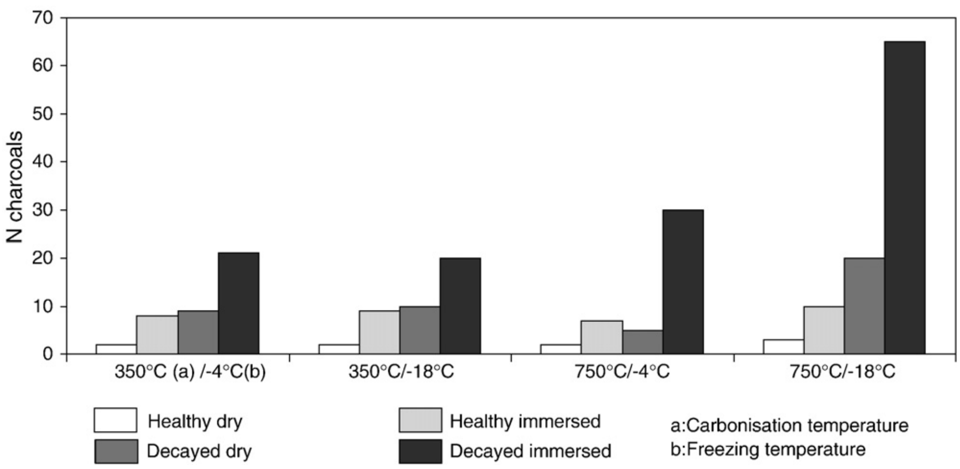

Fig. 12. Fragmentation of charcoal pieces under freeze–thaw processes: for equal condition of combustion and freezing, experimental simulations of freeze–thaw processes have shown that charcoal resulting from the combustion of decayed wood, which is more porous, show a greater and faster fragmentation as well as a decrease in the size of micro-charcoal, whereas the combustion of healthy wood produces charcoal dust with preservation of the initial core.

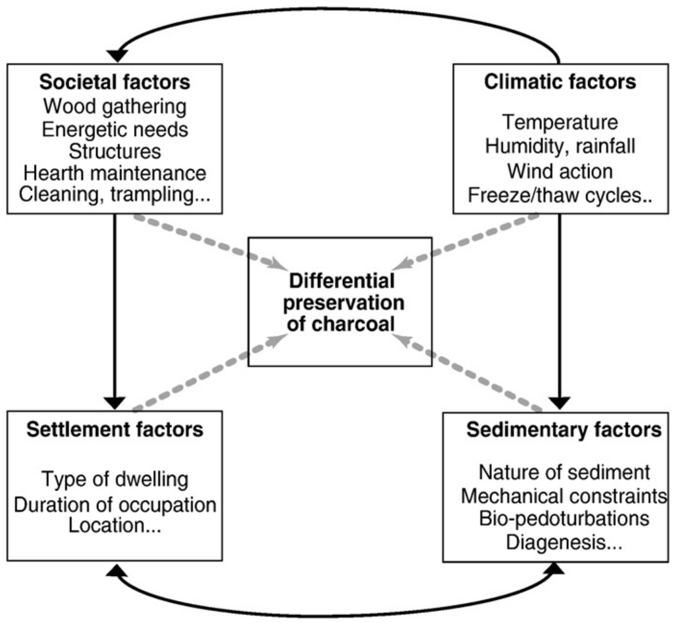

Fig. 13. Charcoal differential preservation: interaction of parameters.

(type of dwelling, site status, duration of occupation, location, climatic factors and sedimentary factors (such as sedimentation rate and nature of sediment). According to this point of view, the combustion process, for instance, depends mainly on societal factors, but also upon climatic and settlement factors. Depositional and post-depositional processes are dependent on all of these factors.

The differential preservation of charcoal and, therefore, our interpretations, depend on the complex interaction of these parameters. Field sampling and quantification methods also condition the representativeness of the charcoal assemblage. The methods and theoretical arguments which validate environmental studies based on charcoal analysis have been defined for more of 20 years. All problems are not solved, such as those concerning the different perception of vegetation in relation to other disciplines, such as palynology. However, the palaeoecological coherence of anthracological studies appears to testify to the high resolution environmental perception.

Reliable palaeoecological studies based on the use of wood will be achieved thanks to these integrated analytical approaches, aiming to understand the full process from the actual wood gathering to the archaeological remains recovered.

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