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Review

Impact of post-depositional processes on charcoal fragmentation and archaeobotanical implications: experimental approach combining charcoal analysis and biomechanics

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ABSTRACT

Generally speaking, charcoal analysis is based on identifying and counting charcoal fragments in order to calculate the relative variations in taxa frequency. All post-depositional processes are likely to induce fragmentation of the anthracological material, raising the question of the representativeness of taxa. Based on an innovative experimental approach combining both charcoal analysis and biomechanics, this paper explores how the mechanical properties of charcoal can influence the fragmentation and the quantification of species in anthracological assemblages. We carried out standardized laboratory compression tests on 302 samples issued from 10 taxa, charred at three different temperatures, in order to characterize the mechanical properties of common species in temperate and Mediterranean Europe. Our results highlight the differential responses of the tested species in terms of resistance to compression and fragmentation, two processes which do not appear to be correlated. Charcoal is very resistant to pressure (up to 22.5 MPa). Our results show that significant fragmentation differences exist between taxa. The total number of fragments after compression is largely dependent on the species, regardless of the charring temperature. However, this interspecific variability is more significant for small fragments [1–2 mm], than for larger fragments [2–4 mm] and >4 mm, with the exception of *Quercus*, which displays differential reactions to compression. Finally, a multifactorial analysis brings to light the impact of the physical and anatomical characteristics of the different species on charcoal fragmentation.

1. Introduction

Charcoal preservation in archaeological sites is variable, even at sites where combustion structures have been identified (Théry-Parisot, 2001, 2010c). According to the current state of knowledge, there is no apparent relationship between charcoal preservation and the sedimentary context. Although this observation does not follow a chronological pattern, it is particularly true for Palaeolithic sites (Braadbaart et al., 2009, 2012; Beresford-Jones et al., 2010; Théry-Parisot et al., 2010a), where identifiable, macroscopic-sized charcoal is at times very rare and/or very altered. In such contexts, charcoal is primarily preserved among the mesoscopic and microscopic unidentifiable fraction (Marquer et al., 2010, 2012), raising the question of the impact of post-depositional processes on charcoal preservation. What are the effects of these processes on anthracological assemblages? Do they have a linear effect on charcoal or are some taxa more fragile than others due to their anatomical structure or chemical composition? This naturally brings us to the question of the representativeness of anthracological assemblages for assessing past vegetation and fuel management.

Since the end of the 1990s, some researchers have focused on a methodical approach to the formation process of anthracological assemblages (Théry-Parisot 1998, 2001; 2013; Théry-Parisot et al. 2010a,b), including (i) human practices, (ii) the physical and chemical modifications of wood during combustion, (iii) depositional and post-depositional processes. Human practices are dependent on non-predictable cultural factors specific to each

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group. On the other hand, combustion and post-depositional processes involve physico-chemical and mechanical transformations, which are independent of socio-cultural contexts, and which affect anthracological assemblages in terms of mass reduction and fragmentation. However, most palaeoenvironmental interpretations are partly based on variations in the relative frequency of taxa, calculated by counting the identified fragments in the studied sample. The effects of combustion on charcoal fragmentation have been the subject of numerous studies (cf. infra). Conversely, the effects of post-depositional processes on anthracological assemblages are not so well documented. However, all processes, from trampling to combustion residue, displacement by humans, weathering, water run off transport, bio or cryoturbation phenomena, alternating freeze-thaw cycles or sediment soaking-desiccation, can induce charcoal fragmentation (for a better overview of sites formation processes see for example Goldberg and Macphail, 2013). In this paper, we address the effects of depositional and post-depositional processes and the resulting potential modification of the assemblages.

The aim of this article is to characterize the physical properties of several common temperate and Mediterranean European species in the laboratory, using appropriate measurements on present-day material. By assessing the differential reaction of each species to mechanical post-depositional alteration processes, we can evaluate the palaeoecological representativeness of the anthracological assemblages. This study involves 302 samples issued from 10 taxa, charred at 3 different temperatures and subjected to standardized compression tests. The results should allow us to assess (i) the question of the mechanical properties of charcoal, (ii) the fragmentation level/rate of charcoal from different taxa and (iii) the modalities of this fragmentation. The main objective of this study is to produce data exposing the intrinsic mechanics of the tested species, to evaluate their conservation potential and to appraise the possibility of the under or over-representation of certain species in archaeological contexts.

2. Research history in charcoal fragmentation

After some pioneering studies (Salisbury and Jane, 1940; Santa, 1961; Vernet, 1973; Thiébault, 1980), methodological reflections on the representativeness of anthracological assemblages began in the 1980s (Chabal, 1988, 1997, 1990; Badal-Garcia, 1990, 1992). The first approach consisted in analyzing the global fragmentation rate and the size of the fragments of the different taxa in archaeological samples. The analysis of Protohistoric archaeological levels (Le Marduel, Lattes, south of France) yielded fragmentation histograms with a Poisson distribution for all the taxa within the same layer. These studies led to the formulation of the "single fragmentation law" hypothesis for all species (Chabal, 1991, 1997). "A posteriori" analysis included the undifferentiated fragmentation stages: combustion, post-depositional processes, sampling and sieving of the material. At the same time, several studies concentrated on the effects of combustion on anatomy and fragmentation (Rossen and Olson, 1985; Smart and Hoffman, 1988; Scott and Jones 1991; Prior and Gasson, 1993; Loreau, 1994; Vaughan and Nichols 1995; Belcher et al. 2005; Lingens et al. 2005; Braadbaart and Poole, 2008; Théry-Parisot and Chabel, 2010). These works demonstrated "the non-linearity of species behaviour towards fire suggesting that combustion is a taphonomic agent, which randomly affects deposits and whose effect on the assemblage is almost impossible to control" (Théry-Parisot et al., 2010a,b). The impact of post-depositional processes on anthracological assemblages is a less-developed aspect of research. Bio-turbation and transport were mainly studied in the domain of pedo-anthracology (Thinon, 1992; Vaughan and Nichols, 1995; Carcaillet and Talon, 1996; Blackford, 2000; Nichols et al., 2000; Scott et al., 2000; Scott, 2010; Carcaillet, 2001). Recent work on the impact of pH and diagenesis on the anthracological material has brought to light a structural alteration of charcoal in alkaline environments (Schiegl et al., 1996; Cohen-Ofri et al., 2006; Rebollo et al., 2008; Braadbaart et al., 2009; Ascough et al., 2010, 2011a,b), but also the strong influence of physical processes on the deterioration of the material (Braadbaart et al., 2009). Among these physical processes, mechanical actions, which directly influence the fragmentation of charcoal, play a preponderant role. Freeze/thaw laboratory experiments, coupled with measuring resistance to compression, have shown that wood alteration ante combustion has a strong incidence on the mechanical resistance of charcoal (Théry-Parisot, 1998, 2001). More recently, a study of the mechanical properties of species from the north of India showed that resistance to compression and the dimensions of the ensuing fragments is correlated to charring temperatures (Lancelotti et al., 2010). Mechanical resistance to compression is higher when compression is applied lengthwise to the cross-section and dense wood is more brittle than less compact woods. In temperate regions, abundant data are available concerning the properties of wood used for construction (Ashby, 2005; Forest Products Laboratory, 2010), but nothing indicates that these data can be transposed to charcoal. For this reason we developed an experimental study of the mechanical behaviour of present-day charcoal to evaluate the fragmentation process of the main species identified in temperate European anthracological assemblages.

3. Materials and methods

The mechanical tests were carried out in the École des Mines de Paris (ParisTech CEMEF- Sophia-Antipolis, France). The aim of these tests was to measure the mechanical response of charcoal to compression and the fragmentation modalities (number and size of fragments). The experimental procedure is based on previous work by Théry-Parisot (1998, 2001)

3.1. Sample preparation

Sample preparation must take account of both the (i) constraints of the shape of the samples used for the mechanical tests and (ii) the effect of the physico-chemical alteration on the mechanical properties of the material during combustion. It generally involves some form of standardization far removed from the reality of the studied archaeological contexts. The samples have to present two perfectly cut parallel sides with no structural, fissure type alteration.

The production of 2 cm cubes, with no charring fissures, is one of the restrictions of our protocol.

The tests concerned charred samples from 10 taxa commonly found in archaeological contexts in southern Europe: *Acer pseudoplatanus*, *Betula pubescens*, *Carpinus betulus*, *Corylus avellana*, *Fagus sylvatica*, *Fraxinus excelsior*, *Populus tremula*, *Pinus pinaster*, *Pinus sylvestris* and *Quercus pubescens*. The dry wood (12% moisture content) is issued from branches with a 10–15 cm section.

3.2. Charring protocol

In order to limit sample deformation during charring, each cube was wrapped in aluminium foil, placed in a porcelain crucible, covered with sand, and then charred in a muffle furnace. The charring temperature has a direct incidence on the mechanical resistance of charcoal (Hillis, 1984; Fengel and Wegener, 1989; Yildiz et al., 2006; Borrega and Kärenlampi, 2008; Gündüz et al., 2008; Mburu et al., 2008; Korkut et al., 2008; Korkut and