Anthracology in the tropics. How wood charcoals help us to better understand today ecosystems

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Anthracology is literally the study of wood charcoals. More precisely, it is dedicated to the identification and interpretation of wood charcoal macro-remains. This term should be preferred to 'charcoal analysis', which also includes the quantification of sedimentary (micro)charcoals used for the reconstruction of past fire regimes. Anthracologists do not seek to reconstruct fire events, but rather, in archaeological contexts, vegetation and/or wood use by past societies.

Charcoals are the remnants of incomplete combustion of lignified plant material (wood) that has burnt under anoxic conditions. This charring process preserves most of the wood's anatomical structures, including vessels, parenchyma and fibres. Charcoals display various patterns, the combination of which is characteristic of genera and species, thus allowing us to ascribe a particular piece of wood charcoal to a particular taxon.

When charcoals are uncovered from natural soils, i.e. out of archaeological contexts, their study is called pedoanthracology, and charcoals are mainly used to reconstruct vegetation changes and treeline dynamics (e.g. Touflan *et al.* 2010).

Wood charcoal is ubiquitous and, as such, represents one of the most common archaeobotanical remains (Asouti & Austin 2005). The identification of fragments found in archaeological sites provides much information on the gathering and selection of wood and on its uses. As such, they reflect the species burnt to achieve different purposes, e.g. domestic, agricultural, funerary, building, etc. Their long-term accumulation in the soils of archaeological sites gives a fairly good picture of the surrounding vegetation at the time, particularly in temperate zones (Chabal *et al.* 1999). In addition, the chronology of the studied sites can be inferred from the radiometric dating of charcoal pieces. When charcoal dating covers a long time span, the taxa recovered in assemblages allow us to reconstruct vegetation changes, which can be natural or due to woodland management.

A few case studies

Anthracology has undergone great developments in temperate countries, especially since the work of Vernet (1973) and of subsequent generations of researchers trained in Montpellier, France. Since then, anthracology has increasingly proven its reliability in reconstructing past landscapes and vegetation use (e.g. Asouti & Austin 2005). Anthracological studies are now being applied to various environments, including in the tropics. In tropical Central Africa, charcoals have been used to detect natural fires and to reconstruct vegetation changes (e.g. Hubau *et al.* 2013), or to confirm the existence of cultivated slash-and-burn fields related to villages (Morin-Rivat *et al.* 2016). In tropical South America – and particularly in Brazil – anthracological studies have been increasingly developed since the 1990s. They have been used to infer climate-related vegetation changes (Scheel-Ybert *et al.* 2003) and to investigate wood gathering and selection for ritual or domestic purposes (Beauclair *et al.* 2009; Scheel-Ybert *et al.* 2014). The discipline is also being developed in Oceania. It has, for instance, highlighted forest management in pre-colonial Kanak sites in New Caledonia (Dotte-Sarout 2017) or firewood use by late Holocene Aboriginal people in Australia (King & Dotte-Sarout 2019). However, to date, charcoals from tropical Asia remain poorly studied.

How to proceed: a methodological overview

There is no standard sampling protocol for tropical areas, let alone tropical rainforests. Despite the obvious interest of working on archaeological sites already identified and excavated (presence of black soils or shards of pottery, as well as living useful plants), tropical anthracologists often have to look elsewhere, as such sites are still rare. They must therefore explore potentially interesting sites in a pedoanthracological way. The sampling mainly depends on logistical and contextual constraints: topography, vegetation and soil types, which define field accessibility and the difficulty of digging.

The size of the sampling plot and the sampling method are determined by the aim of the study and by soil type (Feiss *et al.* 2017). While sampling along transects across ecotones is suitable for assessing treeline dynamics, a 1-hectare plot is more reliable for a palaeoenvironmental reconstruction (as for forest inventories). Prospecting can be done by digging small test pits, as illustrated in Figure 10.1, to assess the distribution and amount of charcoal pieces. The distribution of pits on the study area may be systematic or guided by previous observations or analyses, such as geomagnetic surveys. The latter are very helpful for detecting soil horizons that have been fire-heated and thus to reveal charcoal-rich deposits (Hounslow & Chepstow-Lusty 2002, Chapters 5). Pits provide a local record of the burnt vegetation and may lead to a species-poor charcoal assemblage, even in tropical rainforests. As their digging takes a lot of energy and time, it is not feasible to multiply them on a given site. Auger sampling is a good alternative to increase the species richness or the number of fragments in charcoal-poor deposits and to cover larger sampling areas (Feiss *et al.* 2017).

Water-sieving the soil samples allows us to reveal charcoal fragments. Identification is possible with charcoal pieces ≥0.5 mm, although a minimum size of 4 mm is more suitable to observe enough diagnostic anatomical features (Chabal *et al.* 1999), especially in tropical areas (Scheel-Ybert 2001). Nevertheless, 2- or 3-mm mesh sieves can be used if charcoal is not abundant in the deposits or if larger fragments are rare. After sieving, charcoal fragments are air-dried, away from direct sunlight to prevent them from bursting.

The validity of any interpretation of the assemblage strongly depends on the number of charcoal fragments identified. Building a saturation curve during sample analysis is recommended by ranking taxa according to their corresponding number of charcoals (Chabal *et al.* 1999). Depending on the taxonomic diversity and spatial extent of the sample, this saturation curve reaches a plateau more or less quickly beyond a certain number of charcoal fragments per sample (Badal Garcia 1992). The latter value is a good compromise which ensures that the sampling is sufficiently representative while limiting the time and effort required for analyses. In temperate areas, this figure is about 300 charcoal fragments per sampling level (Chabal *et al.* 1999), whereas in tropical areas Scheel-Ybert (2002) showed that about 200 to 300 fragments are sufficient.

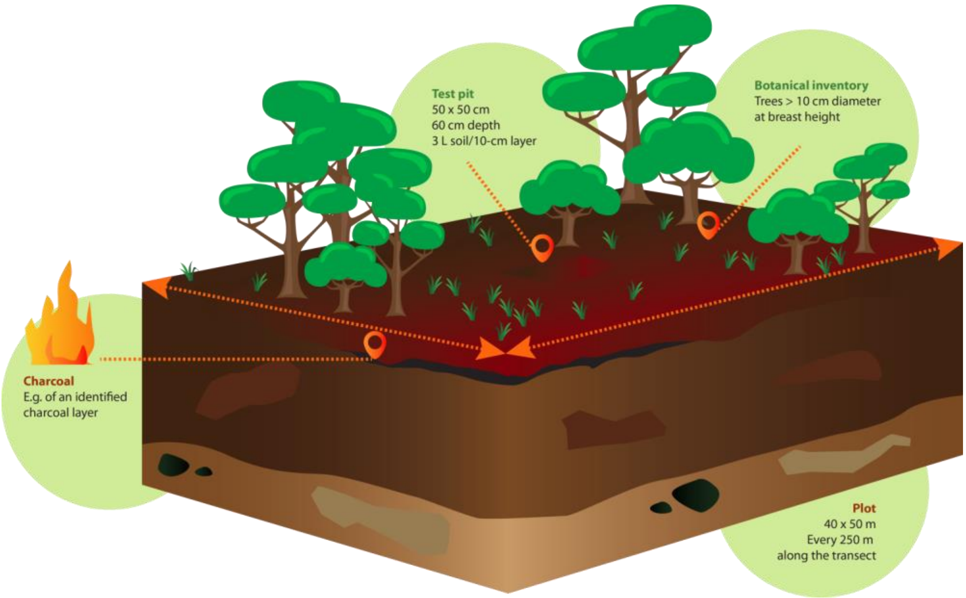

Figure 1 Example of a sampling design using test pits (after Morin-Rivat *et al*. 2016). Source: © J. Morin-Rivat).

Identification

Preparation of wood charcoal for identification simply consists of breaking charcoal pieces by hand, following the three anatomical sections of the wood: transverse (which provides up to 70% of the anatomical information), longitudinal tangential and longitudinal radial (Figure 10.2).

Description of the anatomical features is then made under a reflected-light microscope using dark and bright fields. Ideally, chemical treatments should be avoided to prevent any problem with ^{14}C dating and because they can dissolve silica bodies, which can be a diagnostic feature. Identification of charcoal fragments is carried out by using atlases and guidebooks (e.g. Détienne & Jacquet 1983, Scheel-Ybert & Gonçalves 2017), computer-aided identification tools (e.g. Bodin *et al.* 2019), online databases on wood anatomy (Wheeler 2011) or charcoal reference collections (Scheel-Ybert 2016). In most cases, the charring process has little impact on wood anatomy, leaving the main features recognisable and/or measurable during observation. Radial cracks (e.g. Théry-Parisot & Henry 2012) and vitrification (McParland *et al.* 2010) are the main structural modifications that may occur during charring. If these deformations are not too important (few cracks and incomplete vitrification), charcoals can still be identified.

Of the numerous tropical tree species, many share similar wood anatomy. Most of the time, the identification of tropical charcoal is restricted to the family level only, as many families are anatomically homogeneous (e.g. Sapotaceae), but groups or types can sometimes be distinguished (e.g. within the large family Leguminosae). Identification at the genus level is possible when the family is anatomically heterogeneous or when it includes a single (tree) genus (e.g. Goupiaceae, Huaceae, Dichapetalaceae, Irvingiaceae). Recent studies have focused on means to facilitate identification in species-rich areas. In Africa, Hubau *et al*. (2013) elaborated on a protocol to help identify and discriminate charcoal types from the Mayombe forest. Höhn and Neumann (2018) also stressed the importance of naming charcoal types for interpretation.

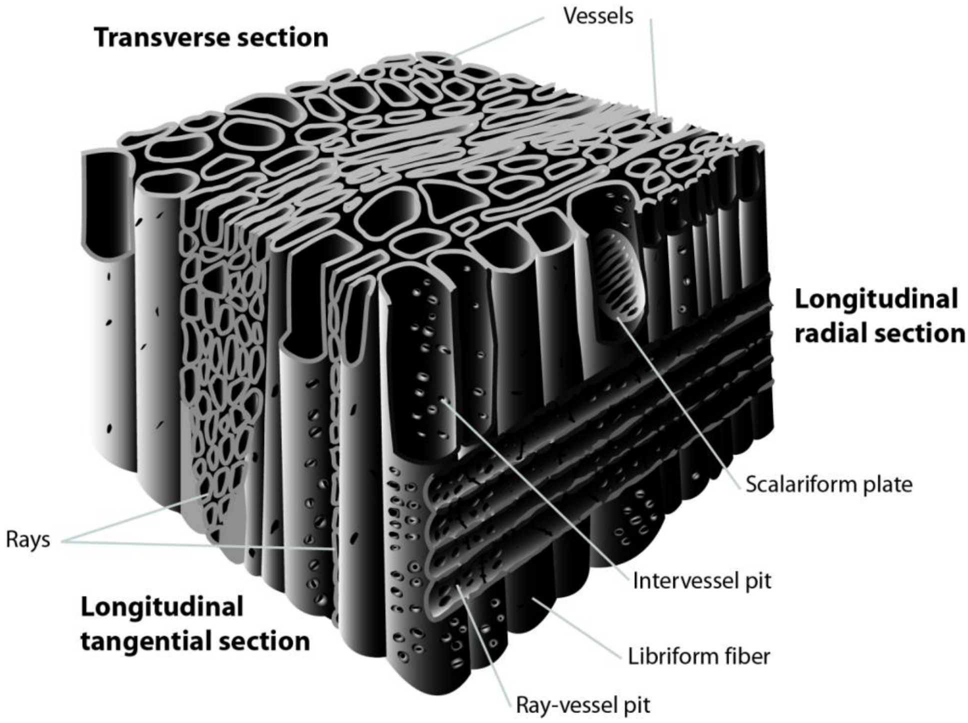

Figure 2 Charcoal fragment observed according to the three anatomical sections: transverse, longitudinal tangential and longitudinal radial. Source: © J. Morin-Rivat.

Charcoals as chronological markers

Wood charcoal is commonly used as a chronological marker because it can be dated by the radiocarbon method. Nevertheless, the fragments to be dated should be chosen with care. To avoid taking into account the age of the old wood itself (Gavin 2001, Morin-Rivat *et al.* 2016), charcoals must come from twigs or from the most external growth rings of larger fragments. Indeed, the ^{14}C age obtained from a charcoal does not correspond to the date of burning, but to the date on which the wood was formed from atmospheric carbon. Thus, if the dating comes from an inner growth ring, it may be several decades, or even centuries, older than the most external growth ring. This can be avoided in temperate woods, where the growth-rings are easily remarkable, but it is more difficult with tropical woods where they are less visible (Tarelkin *et al.* 2016).

Conclusion

Anthracology has proved its reliability in helping us understand how today's ecosystems have become what they are. It is complementary to other bioindicators used for palaeoenvironmental reconstruction, such as pollen and phytoliths (e.g. Robin *et al.* 2012) or to isotopic analyses (Scheel-Ybert *et al.* 2003). Anthracology only gives an image of burnt vegetation, but it often allows a more precise local-scale reconstruction of past woody landscapes than other proxies, which is particularly valuable in species-rich areas such as the tropics. In Amazonia, hundreds of hectares of *terra preta* are enriched with charcoal (Glaser & Birk 2012). There is no doubt that in-depth anthracological studies of these anthropogenic soils will bring insight into their formation and on the societies that produced them.

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