Soil charcoal analysis: a tool to investigate non-linear abrupt changes in ecosystems

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Summary: *Soil charcoal assemblages' constitution and archiving happens connected to the stratigraphical record from non-linear erosion events in a changing ecosystem. Those events are enabled by a change in vegetation cover, for example due to fire events. The resulting deposits are charcoal enriched. They form the here discussed sediment material from case studies used to show that the combination of geomorphological and soil charcoal analysis provides a promising approach to reconstruct non-linear abrupt changes of ecosystems dynamics.*

Key words: *soil charcoal analysis, geomorphology, erosion/deposit, non-linearity, fire event*

INTRODUCTION

Since its establishment as a new palaeoecological approach (Thinon, 1978), soil charcoal analysis (i.e. pedoanthracology) has been increasingly developed over the last decades. However, most of the works done so far deal with particular localized issue and/or with particular investigation areas, especially where fire occurrence is well known as a natural component of the ecosystem dynamic change through time (Ohlson and Tryterud, 2000; Vernet, 2006). However, it can be observed that 'there are charcoal pieces everywhere, in any type of soil'. This observation combined to the palaeoecological insight which possibly can be drawn from this approach (i.e. fire history and past forest vegetation reconstruction) at local scale (i.e. 'mega-charcoal' records), makes the soil charcoal investigation relevant for reconstructing ecosystem dynamics, especially in interdisciplinary approaches (Nelle *et al.*, 2010). However, an important aspect is limiting the interpretation of soil charcoal assemblages: Palaeoecological investigations are based on 'well' established chronological frameworks like chronologically stratified sediments, archiving several types of palaeo-indicators. Such materials allow establishing with a reduced number of dating a temporal framework for the palaeo-data, notably by depth/age modelling. This is very difficult to be obtained from soil charcoal assemblages. Indeed, the quantitative and qualitative analysis of the soil charcoal assemblages is delicate to be chronologically interpreted, since soils are a dynamic archiving context (Carcaillet, 2001). But this does not mean that soil charcoal analysis is out of interest to reconstruct the history of past ecosystems.

The research presented in this communication aims to illustrate how relevant and reliable the strong correlation of soil charcoal and geomorphological analysis is to the reconstruction of non-linear abrupt changes in ecosystems.

DISCUSSION BACKGROUND

Soil formation processes, and especially those implicating the mixing of soil materials soil materials, have an important role in the charcoal pieces vertical distribution. Trees uprooting is an important example. This process possibly mixes important volumes of soil, along a considerable depth in the soils (Šamonil *et al.*, 2010). Additionally, bioturbation processes are to be mentioned, probably as the main soil mixing factor, mainly due to earth worm activity (Jégou *et al.*, 1998). Because these processes are not linear ones, the charcoal incorporation in *in situ* formed soil is not occurring linearly through time. The charcoal incorporation into the soil matrix seems to be more a 'mixing' process. So, to obtain a reliable chronological framework from soil samples it would be necessary to date all the extracted charcoal pieces, to establish the chrono-stratigraphy of the palaeo-indicator itself, instead of the archiving context. This is of course not realistic. Nevertheless, soil charcoal analysis is a relevant and reliable tool to detect and analyze non-linear abrupt changes in ecosystem dynamics: once embedded in the soil matrix, erosive intermittent events might transport the charcoal over variable distances and subsequently deposit a mix of charcoal and transported sediment. These deposits constitute an interesting archiving context to soil charcoal records, and in general to many types of biotic indicators (Bork and Lang, 2003). Like the processes of soil formation, those erosive events are not linear and non-predictable events since they are often a result of a changing vegetation cover, which itself does not follow linear and predictive processes: land cover change is a consequence of ecosystem disturbance, which is an unpredictable event of total or partial destruction of the biomass of the ecosystem, over various temporal and spatial scales (Pickett and White, 1985). However, climatic cycling is an important driver of erosive phases on longer temporal scale, by inducing natural change in vegetation land cover when causing forest canopy retreat. And even at the scale of an interglacial stage like the Holocene, such climatic cycles ('Bond events') can cause a natural change in vegetation cover and eventually erosional processes.

Nevertheless, during the Holocene most of vegetation cover changes are due to human activities (e.g. land use changes), with an increasing impact concomitant to human society development. These changes of land vegetation cover and their consequences on soil erosion are strictly not predictable and not linear. In the process of human induced and natural vegetation cover change fire has been, and still is, the reason for a drastic, abrupt, change of vegetation cover (e.g. forest opening). A strong correlation is established between a fire event, producing charcoal, and the happening of an erosive event, caused by the total or partial vegetation cover destruction (Fig. 1). This 'chain effect' is crucial to both: the constitution of most of the soil charcoal assemblages, and consequently of the soil charcoal record interpretation.

FIGURE 1. Charcoal flow in burnt catchment. Australia 2009.

Soil charcoal analysis must therefore be strongly correlated to soil historical and geomorphological perspectives because i) soil analysis and geomorphological approaches may provide crucial support to the soil charcoal assemblage interpretation by detecting soil horizon resulting from erosion/deposit events, like alluvial or colluvial sediments, and ii) the chrono-stratigraphical record (established by archaeological/OSL/14C dating) enables a chronology, which can support the dating of the charcoal record. Consequently, charcoal assemblages extracted from sedimentary layers could be correlated to the chronological frame obtained, and evermore charcoal pieces may serve to the dating, as very relevant and reliable datable material. Also a soil charcoal dataset including taxonomical and quantitative data of charcoal concentration serves soil historical and geomorphological investigation by providing an insight into the burnt land cover vegetation types.

CASE STUDIES

Two examples from Central and Northern Germany illustrate that the sedimentologically reconstructed and dated non-linear erosive events reflect a consequent soil charcoal quantity and local vegetation composition. At each of these sites, palaeoecological investigations have been done about past soil history with the identification, dating, and in some case the quantification (i.e. sediment budget) of colluvial layers, in soil sequences (i.e. profiles). From those colluvial layers soil charcoal assemblages have been extracted to investigate past fire history (i.e. fire regime) and past forest composition (i.e. the burnt material), based on soil charcoal quantification (i.e. concentration) and wood charcoal taxonomic identification.

These illustration cases support the great interest and perspectives of the combined approach of soil charcoal and geomorphologic analysis to palaeoecological reconstruction.

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