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Fuel origin and firing product preservation in archaeological occupation contexts

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ABSTRACT

We intend here to examine the range of factors involved in the preservation at short to long-term of firing byproducts with respect to the nature of combustion processes and the fuel origin. Our objective is to refresh the cultural and palaeoenvironmental relevance of combustion deposits.

The study is based on the comparison of two recent situations of natural fires and a selection of well preserved firing records from rockshelters and caves in diverse geographical and cultural contexts. The recent analogues comprise a two year investigation of the 2012 July large forest fire at Alt Empordà (Northern Cataluña, Spain) and a study of the 2014 lightning struck pine tree (Allanche, Cantal, France). In situ characterization at micro to nanoscale of firing products has been performed using the SEM–EDS in backscatter mode on individual grains and composite aggregates which were extracted by gentle water-sieving from combustion microstrata and firing products meticulously sampled in the field.

The survey of the Alt Empordà firing record confirms the rapid loss of intact ashes and heating scars, leaving after two years a regenerated soil without any obvious evidence of this fire, except for scattered charcoal.

The study of Allanche lightning struck pine tree shows that lightning produces a suite of robust components diagnostic of flash-heating and plasma-assisted combustion: polymer filaments, vitreous char, metal coatings and singular minerals. Their durability expresses the refractory and hydrophobic properties of materials formed by transient heating and plasma processes. The identification of similar robust components in all the firing products of the archaeological contexts tested here shows that plasma-assisted combustion and flash heating exert a major role on the durability of firing records. The archaeological combustion contexts are separated into two types of intact firing records: (1) the ones with abundant mineralised charcoal, vitreous char and metal coatings would trace the use of fuel acquired from wood affected by a lightning strike; (2) the thick white ash with polymer films, refractory minerals and metal coatings would indicate wood fuel collected during periods of active aeroplasma processes in the atmosphere due to increased dust loading and intense ionization.

The study is suggested to offer a challenging perspective to elucidate further the role that lightning and plasma processes exerted on ancestral pyrotechnology by occasionally providing wood fuel resources of long durability, low degradability and high calorific power.

1. Introduction

The central role of hearths in the social organization of daily domestic activities in occupation has motivated decades of research in high resolution spatial excavation (Vaquero et al., 2004; Meignen et al., 2007; Carbonell, 2010; Goldberg et al., 2012; Vallverdú et al., 2012). From the early emergence of fire use to its fully matured control, hearths have thus been viewed to providing unique data related to the exact duration of occupation and its relevance with respect to site function, particularly seasonal camp, or semi-permanent settlement (Alperson-Afil et al., 2007; Goldberg et al., 2009; Roebroeks and Villa, 2011; Sandgathe et al., 2011; Wadley et al., 2011; Wadley, 2012). The persistence through long occupation sequences of a stable spatial pattern of hearths and associated firing features is often investigated so as to trace the long term continuity of hunter–gatherer occupational behaviour (Karkanas et al., 2007; Mallol et al., 2007; Shahack-Gross et al., 2014).

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Indisputable hearths with their well preserved firing deposits and features of note (e.g. hearth constructions, and hearth deposit-rubefaction) have been widely accepted to represent "intact combustion features" showing "byproducts of burning in stratigraphic position within the original burning locality" (Rigaud et al., 1995; Mentzer, 2014). Firing processes have thus been implicitly assumed to favour durable fossilization of human-related combustion products, in an even more efficient way than instantaneous burial by volcanic ash fall for instance. Meanwhile, human actions along with fire-related activities, i.e. hearth maintenance or dispersion by trampling, together with post-depositional disturbances are widely viewed as the main processes leading to obscure the firing record (hearth stratigraphy); these can lead to a total loss of evidence in some circumstances (Courty et al., 1989; Karkanas et al., 2000; Roebroeks and Villa, 2011; Henry, 2012; March et al., 2014). At our present level of understanding, the apparent discontinuous occurrence though time of hearths or basic combustion markers (charcoal, ashes, burnt artefacts), particularly for the Neanderthals, which was shown to be not reflecting differential preservation or occupational factor was viewed as the consequence of unskilled fire makers who would have relied on natural fires from lightning strikes for only occasional use of fire-related activities (Sandgathe et al., 2011).

On the other hand, geological archives are known to display well preserved combustion features only when fires were caused by lightning strikes (Clark and Harris, 1985; Harris and Isaac, 1997; Scott, 2000; Henry and Théry-Parisot, 2014). In the case of lightning, the marked reddening visible in the field as domains, lenses, or distinctive strata would relate to the strong oxidation of iron compounds under unrestricted air supply due to high rate degassing (CO, H_2) which is irreversible even at geological timescales (Grapes, 2006). In contrast, the rubefaction often encountered at the periphery of hearths and also as a distinctive fine strata underlying the layer of combustion products is generally assumed to reflect the dehydroxylation, structural breakdown and phase transformation of soil minerals (Fe-oxides, clay minerals) and which are assumed to be irreversible under prolonged heating at temperature above 400 °C (Schwertmann, 1984; DeBano et al., 1998; Certini, 2005). However, the study of this kind of intense rubefaction obtained by long term conventional heating for a few days in controlled modern wood fires has shown its rapid degradation by surface pedogenic processes within months, then its total dilution in the regenerated top soil within less than two years (Courty, 2012). This controlled modern wood fire which was performed in a well protected situation, with moderate alteration and weak erosion, has shown the total disappearance of the 10 cm thick microstratified charcoal-rich ash layer after two years, due to surface colonization by cryptogamic vegetation and rapid regeneration of a charcoal-free humus top soil (Courty, 2012). Our results are consistent with most studies dealing with carbon sequestration which have established the fast vulnerability of biochar to loss by decomposition in the subsurface horizons and erosion when not worked or translocated to a greater depth under various soil conditions (Lorenz and Lal, 2014). Therefore, in spite of many laboratory experiments, the exact firing conditions and/or the type of pyrogenic products which would persist beyond centennial scales similarly to the ones encountered in archeological contexts have not been so far elucidated (Hockaday et al., 2007; Singh et al., 2012; Mallol et al., 2013). A series of recent local debris air-falls which delivered unusual carbonaceous materials formed in the atmosphere by plasma processes and derived from biomass burning aerosols, were studied (Courty and Martinez, 2015). These findings urge us to re-investigate the puzzling long-term preservation of firing byproducts in archaeological contexts. The unexpected occurrence in these exceptional recent debris fall of polymers and vitreous char that are similar to the unusual components that we formerly identified in well preserved hearths and charcoal-rich anthropogenic living floors (Courty et al., 2012; Courty and Coqueugniot, 2013) has provided the required modern analogue to question the exact linkages between fuel origin, combustion processes and ancestral fire-related activities.

We present here a study aimed to understand further the range of factors involved in the preservation of firing byproducts. The analytical study focuses on three questions: (1) Is the short-term preservation of firing records related to particular combustion processes? (2) Up to what extent does the fuel origin influence the long-term preservation of firing byproducts? (3) What is the relevance of well preserved firing records encountered in archaeological contexts with respect to fuel origin and combustion processes?

2. Firing contexts and methodology

Recent firing deposits from well controlled natural combustion events are compared to firing records from archaeological hunter–gatherer rockshelters in various habitation settings. In the field, these diverse contexts display similar combustion facies and associated firing byproducts at local scales.

2.1. The 2012 July large forest fire, Alt Empordà (Northern Cataluña, Spain)

This event was accidentally initiated at local spots on July 23rd in Spain, then rapidly spread due to violent winds. After a few days of intense burning, 14 000 ha consisting of a typical mixed Mediterranean shrubland forest were left devastated, while agricultural lands and villages were less affected due to aerial protection by the fire fighting services. This event was one of the most disastrous in a region long known to be regularly affected by wildfires due to dry summers. A first study was conducted on mid August in the fire-affected region that was left still intact in the absence of rainfall since the July event. Two spots showing an intense calcination of the upper vegetation, a total calcination of the surface vegetal cover, intense rubification of the top soil and massive charring of tree trunks were selected: one centred on oak trees, the other one on pine trees. The pattern of combustion features with their associated firing byproducts was studied from the surface down to the unburnt surface soil horizons and selectively sampled. Since then, the short-term evolution of the combustion facies and firing byproducts at the two pilot plots were followed by digging small sections in the burnt soils at the end of the summer season with selective sampling. The trees at the two pilot spots did not show evidence of lightning strikes before or after the 2012 July large forest fire. The region displays shallow coarse textured loamy-sand soils developed on schist parent materials, of low water holding capacity, with a weakly acidic (pH 6.5) forest mull humus, low organic matter content and increased acidity with depth.

2.2. 2014 pine tree struck by lightning (Allanche, Cantal, France)

The studied location concerns an isolated pine tree on a small granite outcrop which was first struck by positive lightning in summer 2013, then sawn down by the forest service. It was again affected in 2014 by a lightning strike that was followed by its combustion two hours later. The surrounding pine trees did not record any damage and the rapid intervention of the fire fighting patrol prevented the fire for spreading. The field study performed during January 2015 allowed the exposure of the burnt soil surface

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