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Burning questions: Investigations using field experimentation of different patterns of change to bone in accidental vs deliberate burning scenarios

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A B S T R A C T

Experimental research into thermal alterations to bone has tended to be carried out under laboratory conditions, where different burning scenarios are simulated to reconstruct the respective heat-induced changes in bone. While this approach has greatly advanced this field of research, very little open-air field experimentation has been conducted and consequently documented. The current paper presents the results of the first study to utilise field experimentation to examine the heat-induced alterations that occur in bone when subjected to two different firing conditions. This experiment contrasted a reconstruction of a funeral pyre with a simulated house fire in order to explore differences in the effects of accidental and deliberate burning scenarios on bone. Both advantages and problems faced are discussed with regards to the methodological approach used to document and analyse the resultant burned bone; leading to recommendations for future research. The burned bone assemblage from the accidental fire displayed uneven burning, with an extensive spectrum of colour alteration. Bone fragments recovered from the funeral pyre however showed distinctly uniform thermal changes, with minimal variation. This research demonstrates the value of field experimentation in the analysis of burned bone from both archaeological and forensic contexts. Insight into both ancient and modern households and their subjectivity to domestic fires, as well as the social and ritual implications of past cremation funerals are considered. It is concluded that future research would greatly benefit from employing a similar mode of investigation, in conjunction with laboratory experimentation.

1. Introduction

Understanding the thermal decomposition of bone is essential for reconstructing the effect of fire on human remains, in both forensic and archaeological contexts (Symes et al., 2015; Gonçalves et al., 2011; Thompson et al., 2016; Ubelaker, 2009). Research in this area has advanced significantly over the past three decades (Collier, 1996; McKinley, 2015) with studies mostly employing laboratory experimentation to examine the macroscopic and microscopic heat-induced (H-I) alterations that occur in burned bone, how they correlate to the temperature and duration of combustion and what techniques best suit their analysis (Ellingham et al., 2015a; Ellingham et al., 2015b; Gonçalves et al., 2011; Gonçalves et al., 2015b; Piga et al., 2009; Thompson et al., 2009; Thompson et al., 2013; Snoeck et al., 2016).

Despite the expanse of research in this field, only a handful of published experiments have been conducted outdoors in open air environments (Downes, 1999; Jonuks and Konsa, 2007; Marshall, 2011; McKinley, 1997; Silva, 2015). These have tended to focus on reconstructing the collapse of the pyre or dwelling, the spread of material in the ground deposit following cremation, or the osteological assessment of the burned bone. As such, the current literature lacks critical documentation and evaluation of this manner of experimentation in general, with specific areas that might benefit from further study including comparisons between different styles of "open-air" burning and also the H-I changes in the bone recovered.

The current paper discusses the results of a pilot study where two deer carcasses were subjected to two differently constructed experimental fires, in order to study macroscopic changes to bone subject to thermal alteration in differing circumstances. The first was a structured funeral pyre, the other a simulated accidental indoor fire using a metal shipping container to represent a generic domestic structure. There were three principle aims to the investigation; firstly, to establish a protocol on how to conduct, record and interpret open-air experimental fires; secondly to document both experiments; thirdly, to investigate how bone responds to opposing firing conditions, one that is managed and one that is left to burn out without ongoing intervention, by

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Fig. 1. Animal bone samples displaying the colour alteration that takes place when subject to extreme heat.

recording multiple H-I modifications in the remnant burnt bone.

1.1. H-I alterations in bone

Certainly, the most widely documented and well-studied macroscopic alteration that occurs to bone when subject to extreme heat is colour change (Delvin and Herrmann, 2015). Research has found that a skeletal element will pass through a sequential spectrum of chromatic alteration, from yellowish to white, which is caused by the combustion of its organic and inorganic components and is subject to oxygen availability (Fig. 1) (Reidsma et al., 2016; Ubelaker, 2009; Ullinger and Sheridan, 2015). When bone is first subjected to heat it changes from its normal ivory colour to brown and then black, caused by the combustion of both carbon and collagen. This is followed by grey which is induced by the polarization of organic compounds, and then white which is caused by the complete combustion of the bone's organic material and the fusion of bone mineral (Ellingham et al., 2015a). This sequence of colour change in bone is always consistent, however different researchers have reported varying temperatures at which these stages are achieved (Ellingham et al., 2015a). Colouration in burned skeletal remains can also be a consequence of staining from minerals within the burial environment or the melting of metal artefacts that are either worn or placed with the individual at the time of incineration (Brady, 2006; Dupras and Schultz, 2013). It is therefore essential to consider the wider context of the burned deposit as well as any extraneous inclusions prior to interpretation.

Further macroscopic H-I alterations that have also been extensively researched include fracture patterning, warping, heat-induced size changes and weight loss (Buikstra and Swegle, 1989; Gonçalves et al., 2011; Gonçalves et al., 2015a; Gonçalves et al., 2015b; Thompson, 2005). Recent laboratory experiments have found that fracture patterning and warping is associated with the preservation of collagen in bone, as well as recrystallization at the inorganic phase, and has allowed researchers to infer pre-burning conditions; namely, the burning of fleshed and dry bone (Gonçalves et al., 2015b; Vasserol et al., 2016). Examining heat induced size change and weight loss has been found to be useful for the analytical assessment of burned bone. The former has been associated with the coalescence of mineral crystals (Gonçalves, 2011), while the latter is caused by the evaporation of water, the combustion of organic compounds and the release of CO_2 (Ellingham et al., 2015b).

On a microscopic level, the ultra-structural morphology of bone also changes when heated (Ellingham et al., 2015a; Piga et al., 2016; Ritchie, 2006; Thompson et al., 2009). The diameter of osteons and Haversian canals within bone shrink, while the size and formation of crystallites, which are made of bone's inorganic component, increase when subjected to higher burning temperatures (Nelson, 1992). Histomorphology has been successfully used to examine these microscopic changes in burnt bone, and has found these alterations to be a sensitive indicator of thermal decomposition (Squires et al., 2011). More recently, studies have experimented with reconstructing the crystallinity indices of burnt bone to infer burning temperatures, including low, medium and high (Thompson et al., 2009; Thompson et al., 2013). The CI index has been found to be the most reliable representation of the crystallinity of burnt bone and has been applied in the analysis of cremated samples from the archaeological record (Thompson et al., 2016).

1.2. Laboratory experiments

From the early 1950s experiments have artificially recreated various firing conditions in order to record the gross changes that bone