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Contextualising the dead – Combining geoarchaeology and osteo-anthropology in a new multi-focus approach in bone histotaphonomy

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ABSTRACT

Histotaphonomy has become an important area of research in funerary archaeology. It focuses on diagenetic alterations in bone microstructure and the reconstruction of post-mortem processes. Microbial bioerosion is the most common diagenetic change observed in archaeological bone, and its probable causes have been the subject of ongoing discussions.

This paper presents a new integrative approach that combines methods from physical anthropology and geoarchaeology. The aim is to contextualise samples in regard to their sedimentary milieu (sediment type), the sedimentation processes they underwent, and the specific archaeological features they originate from. The analysis is based on 208 human and animal skeletal fragments from the Late La Tène site of Basel-Gasfabrik recovered from various feature types and embedded in different sediments. Both 80 µm and 30 µm thin sections were graded semi-quantitatively on a scale of 0 or 1 to 5 in regard to bacterial attack (BAI), Wedl tunnels (WTI), cyanobacterial attack (CAI), the formation of cracks (CRI), the collagen content (COI), and thermal alterations (HEI).

Our results evinced no correlations between the intensity of bacterial attack and sediment types or sedimentation processes respectively. We therefore deduce that bacterial degradation of bone is mainly caused by endogenous gut bacteria. Wedl tunnels, on the other hand, are chiefly found in bones from exposed surfaces. Bone collagen content, as measured by birefringence, is dependent on a variety of factors, with thermal alteration being among the most important. Unlike the 80 µm sections used in anthropological investigations, the 30 µm thin sections typically utilized in geoarchaeological analyses permitted a reliable distinction of microbial bioerosion types. Our context-oriented histotaphonomic approach allows detailed conclusions on the causes of microbial bioerosion in bone. Moreover, it provides an important tool for reconstructing the post-mortem biographies of human and animal remains, especially in regard to (multi-stage) mortuary practices and the analysis of sedimentation processes. Thus, this novel approach generates a wealth of information from individual skeletal elements as well as from bone fragments embedded in soil samples.

1. Introduction

Histotaphonomy is a field of research related to forensics, physical anthropology and palaeoenvironmental investigations, and is concerned with the description, evaluation and interpretation of taphonomic processes in bone on a microstructural level (Bell, 2012a; Jans, 2013; Turner-Walker and Jans, 2008). It provides information on the post-mortem fate of human or animal bodies (death history), on the embedding of bones into the soil, on their sedimentary milieus as well as on post-sedimentary processes. Here, we apply a new approach to assessing the complex interplay of factors affecting the diagenesis of human and animal remains. By combining anthropological and geoarchaeological approaches with histotaphonomy, a

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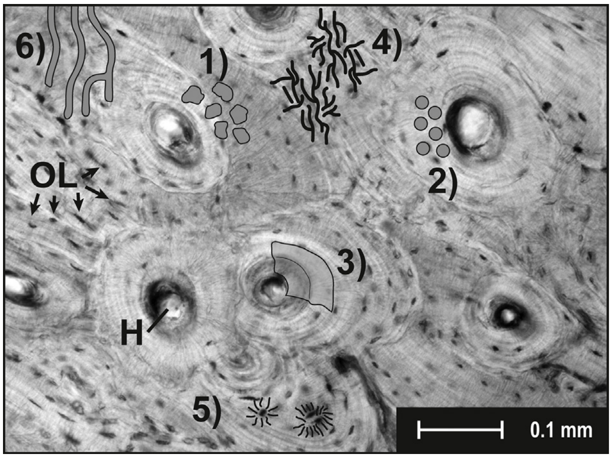

Fig. 1. Schematic representation of bioerosive features in bone: 1) budded *mfd*; 2) linear longitudinal *mfd*; 3) lamellate *mfd*; 4) Wedl tunnelling; 5) enlarged canaliculi (Wedl type 2); 6) cyanobacteria tunnelling. Note the numerous Haversian canals (H) and osteocyte lacunae (OL).

variety of questions can be addressed. These include the reconstruction of mortuary practices as well as the identification of animal sacrifices, interpreting (human and animal) depositions, and more generally, the handling of bones as waste, technical raw material, and/or as objects of symbolic value. Thus, histotaphonomy becomes an effective tool not only in funerary archaeology but also for the reconstruction of domestic and/or ritual activities. The Late La Tène site of Basel-Gasfabrik (Switzerland) served as a case study since it has been intensely studied and provides comprehensive (bio-) archaeological, archaeoanthropological and geoarchaeological data.

1.1. The development of histotaphonomy

Initial histotaphonomic observations go back to the 19th century, when Carl Wedl described microstructural changes in a human tooth caused by microbial activity (Wedl, 1864). The actualistic experiments of Johannes Weigelt and Ivan Efremov in the first half of the 20th century established the term "taphonomy" in histology (Weigelt, 1927; Efremov, 1940). From the second half of the 20th century onwards, microbial bioerosion in hard tissues was studied systematically (Bell, 2012a). At that time also, Cecil J. Hackett first described three other microbial phenomena in bone in addition to the so-called Wedl tunnels (Hackett, 1981). These microbial bioerosion patterns are collectively called *microscopical focal destruction* (mfd) and include *linear longitudinal*, *budded*, and *lamellate mfd* (Fig. 1). Robert E. M. Hedges and Andrew R. Millard developed the *Oxford Histological Index* (OHI), a well-established tool for assessing bone preservation semi-quantitatively (Hedges and Millard, 1995; Millard, 2001). In the OHI, bones are graded on a scale of 0–5 depending on the percentage of their microstructure that is free from microbial bioerosion (Table 1).

Table 1
Oxford histological index (OHI) after Hedges and Millard, 1995, Table 1.

OHI	% intact bone	Description
5	> 95	Very well preserved, virtually indistinguishable from fresh bone
4	> 85	Only minor amounts of destructive foci, otherwise generally well preserved
3	> 67	Clear preservation of some osteocyte lacunae
2	< 33	Clear lamellate structure preserved between destructive foci
1	< 15	Small areas of well-preserved bone, or some lamellar structure preserved by pattern of destructive foci
0	< 5	No original features identifiable, other than Haversian canals

In archaeology, histotaphonomic research was pursued intensely over the past 20 years. The main focus has been on human remains (Bell and Elkerton, 2008; Booth, 2014, 2016; Booth et al., 2015; Booth and Madgwick, 2016; Jackes et al., 2001; Hollund et al., 2012; Turner-Walker and Jans, 2008; Turner-Walker and Mays, 2008), while animal bones from archaeological contexts have been analysed only rarely (Huisman et al., 2017; Jans et al., 2004; Jans, 2005; Müller et al., 2011; Nielsen-Marsh et al., 2007). There are, however, a number of studies that have examined microbial bioerosion in modern animal bones (Fernández-Jalvo et al., 2010; Fernández-Jalvo and Andrews, 2016; Kontopoulos et al., 2016; Nicholson, 1996, 1998; Turner-Walker and Peacock, 2008; Turner-Walker, 2012; White and Booth, 2014).

Until the 1990s, post-mortem diagenetic alteration of bone – and therefore also microbial bioerosion – was perceived as a post-sedimentary process which took place only after skeletonisation. It was thus (implicitly) assumed that microbial degradation could not stem from other factors such as putrefaction during the early phases of decay (Bell, 2012a). The first ones to challenge this assumption were Lynne S. Bell and others (Bell et al., 1996; Child, 1995). Based on SEM observations, Bell concluded that certain microbial changes in bone occur already during the first few days or weeks after death, induced by endogenous gut bacteria. The idea was taken up and further developed subsequently (Jans et al., 2004; Jans, 2013; Nielsen-Marsh et al., 2007; Trueman and Martill, 2002; White and Booth, 2014). It regards the intensity of bacterial attack as an indicator of the early post-mortem biography of the body, which represents a novel approach to the reconstruction of mortuary practices (Booth et al., 2015; Booth and Madgwick, 2016; Hollund et al., 2012; Jans, 2013). Other authors however suggest that bacterial decomposition is largely due to soil micro-organisms and therefore dependent on exogenous factors (Grine et al., 2015; Kendall et al., 2018; Kontopoulos et al., 2016; Morales et al., 2017; Turner-Walker, 2012).

1.2. Histotaphonomy in archaeoanthropology and geoarchaeology

There are some fundamental differences between histological research in physical anthropology and geoarchaeology in regard to topics, methods and the collection of data. Anthropological bone histology focusses on the human individual or on a precise skeletal element, while (archaeological) contexts and specific sediment characteristics are rarely taken into account. Bones are usually histotaphonomically analysed using a polarisation microscope and thin sections (Jans, 2013; Portmann et al., in prep.), by scanning electron microscopy (SEM) (Bell, 2012a, 2012b), or by microtomography (micro-CT), which permits examination of complete bone specimens (Booth et al., 2016). While SEM images offer high resolution even under high magnification, thin sections have the advantage of making changes in colour visible (e.g. due to thermal alteration or staining) and, with the aid of a polarising filter, permitting an assessment of collagen content. Here, skeletal elements and section planes are selected deliberately. Microbial degradation is commonly assessed using either the *Oxford Histological Index* (OHI) (Hedges and Millard, 1995; Millard, 2001) or the *General Histological Index* (GHI) (Hollund et al., 2012). Both indices rate the degradation *in toto* without distinguishing between specific kinds of microbial erosion. However, as particular taphonomic indicators like *microscopical focal destruction* (mfd), cracks, and collagen content can be traced back to different causes, Miranda Jans suggests a more detailed assessment of the different phenomena (Jans, 2013).

Micromorphology, an analytical technique in the frame of geoarchaeological research, examines (archaeological) sediments and features using soil thin sections. In general, bone is not specifically targeted in such analyses; instead, small bone fragments and splinters may be included at random in such thin sections as components of archaeological layers. Section planes, skeletal elements and species identity of the included bone fragments are unknown and incidental. It is not always possible to distinguish human and animal bone, and