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The application of histomorphometry and Fourier Transform Infrared Spectroscopy to the analysis of early Anglo-Saxon burned bone

ABSTRACT

Macroscopic examination, histomorphometry and Fourier Transform Infrared Spectroscopy (FTIR) are applied to the analysis of burned bones from the early Anglo-Saxon cemetery at Elsham in Lincolnshire, UK. These methods were undertaken to gain a greater understanding of pyre conditions from an archaeological context and the effects of burning on bone microstructure. Sixteen samples were employed for thin-section analysis while eight samples were used with FTIR. The results suggest that these methods correspond well with macroscopic examination, though anomalies did occur. The techniques employed in this paper have demonstrated that the temperatures reached on the funerary pyres at Elsham ranged from 600°C to over 900°C under oxidizing conditions.

Keywords: burned bones; FTIR; histomorphometry; Anglo-Saxon; Elsham

1. Introduction

The early Anglo-Saxon period is known for its rich burial assemblages and large inhumation and cremation cemeteries. These cremation cemeteries are concentrated in eastern England, among the largest and best studied are Spong Hill, Norfolk, Sancton I, East Riding of Yorkshire and Loveden Hill, Lincolnshire (Fennell 1964; Timby 1993; McKinley 1994). Furthermore this region holds the most evidence for the practice of cremation funerary rites between the fifth and seventh centuries AD, though inhumation has a more generalised distribution. In the majority of areas, inhumation and cremation were carried out alongside each other. Unfortunately, cremated bones that were excavated from these cemeteries have long been neglected on the basis that little information could be extracted from these remains (Myres 1947, 2). However, over the past twenty years interest in Anglo-Saxon cremation cemeteries has significantly increased. This new found attention appears to have been a result of methodological advances in biological anthropology to assess the demographic and life history attributes of such sites. Generally, these studies have failed to incorporate more technical analyses. A more nuanced understanding of how the analysis of heat-induced change in bone can provide valuable information about pyre technology and the funerary process. Subsequently, the use of these methods would allow a greater insight of the cremation process and its effects on human bone and has been demonstrated by studies of skeletal material from other periods and from forensic contexts (Table 1).

Table 1

A common method employed to assess pyre conditions is macroscopic examination of cremated bone. The main focus of such analysis explores the colour of bone to determine the temperature range and oxidising conditions of the funerary pyre. Insufficient oxygen would have created a reducing, rather than oxidizing atmosphere, thus the bone would have been charred and appear blue to grey in colour as opposed to oxidizing conditions in which the bone would turn a buff to white colour (McKinley 2000, 405). Shipman, Foster and Schoeninger (1984, 312-313) devised five distinct groups based on the heating stages of bone tissue and the resulting colours at different temperatures ranging from pale yellow through brown, black, bluish grey, light grey and white. Nonetheless, it has been noted by a number of authors that colour is a poor criterion in judging the degree of incineration and the examination of colour alone cannot determine the attained temperature of a cremation pyre as heat varied throughout the structure (Herrmann 1977;

Thompson 2004). Furthermore the colour of bone may have changed after deposition in the ground (Taylor, Hare and White 1995, 116). More recently Munro, Longstaffe and White (2007) explicitly associated colour change with temperature of burning. Most significantly, Walker, Miller and Richman (2008) have improved our understanding of the relationship between the colour of cremated bone and temperature, duration of burning, availability of oxygen and organic compounds through evaluating RGB values of postcremation digital images. Despite the advances currently been made regarding the colour of cremated bone, macroscopic and microscopic analyses need to be employed in conjunction to gain a more comprehensive picture of pyre conditions (Thompson 2004; Walker, Miller and Richman 2008, 134;).

The use of histomorphometry was highlighted by Herrmann (1977) and Bradtmiller and Buikstra (1984), who drew attention to a number of structural changes that occurred as a result of the burning process – although this has not been developed significantly since. Together with macroscopic examination, thin-section analysis is extremely useful as structural changes of cremated bone can be observed at various stages of the cremation process. This can provide a better sense of the temperature that funerary pyres reached in a way that examining the colour of the remains alone cannot. This method can also show how long a cadaver had been left on a funerary pyre; for instance if high temperatures were reached, though the corpse was only on the pyre for a limited amount of time, the cortical bone underlying the periosteal surface would show reduced organics while bone in the endosteal region would show better preserved microstructure as this area of the bone had not been exposed to such high temperatures (Walker, Miller and Richman 2008, 130). Conversely, the fragmentation, fracturing and disturbance of bones on the pyre (as a result of possible tending) would have caused the endosteal bone to have been directly exposed to the fire and would not necessarily be better preserved than the periosteal surface (McKinley 1989, 72). This has implications for the determination and interpretation of wealth or social status in Anglo-Saxon communities that practised cremation rites. It may be possible that they invested more resources, including time and fuel, into the cremation process and burial of a prominent member of the community. The major problems with this technique is the fragile nature of cremated bone which often crumbles when attempting to cut thin-sections combined with the specialist nature of the equipment and expertise required. These kinds of issue may deter osteologists and archaeologists from carrying out this method as it is prohibitively time consuming. McKinley (1994, 17) noted this problem when discussing the Spong Hill material. Despite excluding the method from her study, the author stated that it is possible to use this technique in conjunction with archaeological material. This is supported by Herrmann's (1977) study that employed thin-section analysis with Iron Age cremated bone samples.

Fourier Transform Infrared Spectroscopy (FTIR) has only recently been applied to the analysis of cremated bones. FTIR produces a spectrum from a given material based on the absorption of infra-red radiation. Key values from peaks along these spectra can be used to create a number of ratios, including the Crystallinity Index (CI) and the carbonate to phosphate ratio (C/P), which can then be used to gain a greater understanding of temperature and duration of the cremation process. The Crystallinity Index, or 'splitting factor', is the more common ratio, and is a measure of the structure order of the crystals within a bone (Trueman *et al*. 2008). When these crystals are heated they become larger and/ or more ordered (Stiner *et al.* 2001, 650). The C/P ratio decreases as a consequence of the carbonate fraction decomposing at higher temperatures (Thompson *et al*. 2009). The examination of these ratios will allow for a complementary interpretation of funerary activity when combined with examining thin-section micrographs, with regards to the temperature and duration of a cremation. The main reason for this is the increasing proportion of the inorganic fraction following loss of the organics as a result of the cremation process. Thompson, Gauthier and Islam (2009, 914) conducted a controlled experiment to investigate the relationship between temperature of burned bone and changes to the structure of the inorganic fraction and concluded that FTIR can distinguish cremated bones from low intensity and high intensity burnings. Interestingly, Thompson *et al*. (2009, 913) also observed that the disappearance of collagen occurred at 700°C. This is noteworthy as other authors, despite employing different methods, have noted that this is the temperature when major changes occur to the bone structure (Herrmann 1977; Newesely 1988; Nicholson 1993; Thompson 2004).

This paper aims to shed further light on early Anglo-Saxon funerary ritual and pyre technology through the combined use of histomorphometry and FTIR analysis, which is yet to be employed in conjunction with cremated remains from this period. The use of these methods will contribute to archaeologists' understanding of the efficiency of these techniques, especially with regards to archaeological and modern material from unknown contexts. The combined use of macroscopic examination, histomorphometry and FTIR analysis have been carried out as the utilisation of histology is rarely incorporated in studies examining other aspects of the burning process, such as duration and temperature of the funerary pyre, yet it could provide a great amount of information (Cunha *et al.* 2009, 5).

2. Materials and methods

The samples selected for this study derive from the early Anglo-Saxon cremation cemetery of Elsham in North Lincolnshire, U.K. (Webster and Cherry 1977; Richards 1987; Bond 1996; Leahy 2007) (Figure 1). All Anglo-Saxon cremation sites are dated between the fifth and sixth centuries, tentatively extending into the seventh century. The entire cemetery was excavated between 1975 and 1976, from which five hundred and seventy seven cremation burials were recovered. The original bioarchaeological assessment was conducted by Mary Harman in 1976 who explored the biological age and sex of the community of the Elsham cemetery. However, as a result of the developments in biological anthropology and more standardised recording techniques, a reassessment of the material was conducted by the first author of this paper. All individuals assessed in this paper were adults based on McKinley's age categories employed in the Sancton I and Spong Hill reports (Timby 1993, 289; McKinley 1994, 19).

Figure 1

A total of three comparative thin-sections of burned bone were prepared by Bhayro (2003) and micrographs of these slides were taken by the primary author. These samples derived from a defleshed adult human femur from a modern anatomical specimen, though its origin is unknown. Each sample was subjected to heating in a Lenton Eurotherm 902P furnace for fifteen minutes at 300°C, 600°C and 900°C, respectively (Bhayro 2003, 25). An advantage of these temperatures is that they closely match those used in other experimental burned bone studies. These comparative thin-sections are stored in the slide collection in the Department of Archaeology at the University of Sheffield. Table 2 shows the details of the three standardised categories employed in this study to classify the changes to bone microstructure as a consequence of the cremation process. These include less intensely cremated, intensely cremated and completely cremated categories. The presence of pyre and artefact debris was also recorded as further evidence of temperature.

Table 2

2.1 Thin-section analysis

Sixteen samples were chosen at random, all of which were taken from single burials (Table 3). The only condition of this sampling method was that the remains were taken from adult long bones as these are the most suited to thin sectioning. These samples were initially cleaned of any dirt that remained on the bone surface. The colour of bone from each sample was recorded using *Munsell soil colour charts* (2000). They were then placed into individual cubes of an ice cube container and a small quantity of LR White resin mixed with a polymerisation accelerator (Agar Scientific) was poured into each individual cube ensuring that the bone was covered. The container holding the samples was consequently placed into a sink of cold water to counter the heat which was produced as a result of the chemical reaction. Once the bone was soundly embedded in the resin each sample was thin-sectioned using a Leica SP 1600 saw microtome at a speed of 600RPM. Sections were cut to either sixty, seventy five or one hundred microns due to the fragile nature of the bone. Once cut, the embedded thin-section was mounted between two glass slides. Micrographs were then taken of the thin-sections to allow analyses of the microstructure of the cremated bone. A Leitz LaborLux 12 Pols microscope was used so that the samples could be observed in plane polarized and cross polarized light. Magnification remained at x25 throughout the process. A Canon EOS300D camera was utilised to capture images of the bone microstructure. The images were then imported on to remote capture software. The microstructure of the archaeological samples was subsequently compared with the experimental specimens, where temperature of burning was known. Other factors such as the presence of pyre debris and macroscopic colour of the bone were considered throughout. Macroscopic and microscopic examinations were employed in this study to gain a better understanding of pyre temperatures during the early Anglo-Saxon period. The use of histomorphometry also aims to show differential burning of the body which may illuminate the position of the individual on the pyre.

Table 3

2.2 FTIR analysis

A total of eight samples were selected at random for this analysis, all of which derived from single burials. Samples were taken from two inhumed individuals (EL76AK; EL76JO), three less intensely cremated (EL75BB; EL75ES; EL76DH), one intensely cremated (EL76PB) and two completely cremated (EL75MQ; EL76NN) from the Elsham assemblage (Table 3). The colour of each bone was recorded using *Munsell soil colour charts* (2000). Each sample was taken using a scalpel from the periosteal surface of the anterior distal third of a femoral diaphysis and was stored in a sealed test tube as recommended by Thompson et al. (2010). Inhumed samples, from the same anatomical locations, were used as a control for the study. The FTIR-ATR method was used throughout this study as it has been shown to be preferred to the traditional FTIR-KBr procedure (Thompson *et al*., 2009). A Nicolet 5700 FT-IR Spectrometer controlled by OMNIC 7.3

software was used in this study. Spectra were recorded between 2000 cm^{-1} and 400 cm^{-1} at a resolution of 4 cm^{-1} and an averaging of 16 scans. Three replicate measurements were made on each sample. To avoid contamination, the diamond stage was cleaned with propanol prior to analysing each sample. After a background spectrum had been collected, samples were, in turn, placed on to the diamond ATR crystal. Once a sample was in place and covered the diamond stage sufficiently, an adjustable clamp was tightened to ensure good contact between the sample and the ATR crystal. Subsequently, spectra were automatically recorded using the OMNIC software. The application of FTIR analysis in this study aims to identify discrete temperature variation between samples, which would not be detected through the use of macroscopic and histomorphometric analysis alone.

3. Results

3.1 Thin-section analysis

The determination of temperature based on bone microstructure examination highlighted that eight of the samples were burnt at a temperature of at least 900°C and thus fall in to the completely cremated category (Figures 3-5). This was displayed by the destruction of organic material and structure of the bone and the fusion of hydroxyapatite crystals, which occurs between 700-800°C. The fusion of crystals is visible by the disappearance of osteocyte lacunae while the diameter of osteons decrease and the diameter of Haversian canals increase in size (Mayne Correia 2006, 279; Fairgrieve 2008, 136). Only two samples exhibit the complete loss of microstructure which occurs at over 900°C, namely EL75BK and EL76CA(a) (Figures 2 and 3). The remaining six samples displayed osteons, which are lost at around 900°C. This highlights that these individuals were cremated on a pyre which reached temperatures of at least 900°C.

Figures 2-3

The remaining eight samples display evidence of burning at lower temperatures and were assigned to the intensely cremated grouping. In all instances this was manifested by the clear presence of osteons in at least one area of the bone section (Figures 4-6). This suggests a temperature of less than 900°C. When compared with the experimental thin-sections it appears that these bone samples from Elsham were cremated at temperatures between 600°C and 900°C.

Figures 4-6

Three of the samples, which were assigned to the intensely cremated category, produced some interesting results. These anomalies are worth investigating further. An intensely cremated radius fragment was selected from burial EL75GA (Figure 7). Under plane polarized light the periosteal region and external cortical bone displays no structure and suggests this area of the bone was heated to temperatures of at least 900°C (Figure 8). A section of the inner cortical bone shows the presence of osteons, and the structure closely resembles that of the experimental section fired at 600°C. However, the endosteum and surrounding area exhibit fewer osteons and less organised structure, indicating the fusion of hydroxyapatite crystals suggesting a temperature of 900°C. Unfortunately a cross polarized micrograph of this sample was unavailable for analysis. Over 50% of the bone microstructure has been destroyed. A number of heat-induced fractures were distinguishable from the plane-polarized micrograph. The bone fragment is black in the central section but is white in the endosteum and periosteum regions, thus the use of both colour and examination of bone microstructure was successful in accordance with Shipman, Foster and Schoeninger's (1984) five stages of burning. Based on macroscopic and microscopic examination, a temperature range of 600-900°C can be assigned to this radius fragment.

Figures 7-8

The sample selected from burial EL75PM(b) (FN 273(b)) was taken from an intensely cremated humerus fragment (Figure 9). Under plane polarized light the central section of this bone displayed many osteons and some degree of structure, though many hydroxyapatite crystals have fused causing a disorganised arrangement (Figure 10). At either side of this section, two dark areas suggested decreased mineral content. This was particularly evident in the periosteal region which could be clearly seen on the cross polarized light micrograph (Figure 11). The endosteal region of bone shows a small number of Haversian systems in an even more disorganised arrangement when compared to the central section of bone, suggesting exposure to higher temperatures and the fusion of hydroxyapatite crystals. Over 50% of the bone microstructure has been destroyed in this fragment. No heat-induced fractures were apparent from this thin-section. The thin-section examined ranges in colour from black to white and corresponds to the bone microstructure accordingly. However, the black central section of bone, towards the endosteum, displays no microstructure and consequently disagrees with Shipman, Foster and Schoeninger's (1984) five stages of burning.

Therefore, based on macroscopic and microscopic examination, a temperature range of 600-900°C can be assigned to this specimen.

Figures 9-11

An intensely cremated femur fragment was selected from burial EL76NN (FN 549) (Figure 12). This was a different fragment from the sample used for FTIR analysis. The majority of the bone structure from this section had been destroyed however two main areas within the bone still possessed some osteons and structure (Figure 13). This was exemplified on the cross polarized micrograph in which some mineral content had survived in the central portion of the bone (Figure 14). Over 50% of the bone microstructure has been destroyed. Some small heat-induced fractures were apparent in the periosteal and endosteal regions of the bone section. The thin-section examined ranges in colour from white to black and corresponds to the bone microstructure accordingly. Therefore, based on macroscopic and microscopic examination, a temperature range of 600-900°C can be assigned to this ulna fragment.

Figures 12-14

3.2 FTIR analysis

Table 4 presents results of the FTIR analyses. As can be seen, there is a general trend with increased cremation intensity of increasing CI and a drop in C/P. This is in keeping with previously published work (such as Thompson et al. 2009; 2010). Despite the relatively large standard deviations present (a likely feature of sample size) it is possible to distinguish archaeological unburned bone from archaeological burned bone. Further, with the combination of CI and C/P, (Figure 15) it is possible to note more subtle differences and distinguish unburned bone from bone burned at low, medium and high intensities.

Table 4

Figure 15

It can be seen that the two inhumed samples are separated from the burned samples. Although there is not a great difference between the CI values for these two inhumed samples and one of the less intensively burned samples, there is a clear difference in C/P values. Indeed C/P values are of greatest use again when differentiating the completely burned samples from the other burned samples. Since there is some debate as to whether CI can be used to accurately predict temperature of burning (Thompson et al. 2009) it has not been used here in this way, however the conclusions of the histological work and the crystallinity ratios are largely in agreement. Furthermore, despite the criticisms already highlighted, colour can be useful as a broad indicator of burning intensity and it can be seen in Table 4 that temperature correlates well with colour which in turn relates well to CI and C/P values. The application of CI and C/P to actual archaeological material is rare, and it is therefore useful to note that the results from these methods correlate well with more established techniques, and therefore contribute a reliable and complementary analysis.

The presence of pyre goods from the Elsham sample was slightly higher among remains that were completely cremated but were not statistically significant, which may be a result of small sample size (Figure 16). 71% of completely cremated burials contained artefacts while 56% of intensely cremated burials contained pyre goods. Of course, some objects may not have been collected and deposited in an urn after the cremation process and are therefore absent from the archaeological record. Based on the lack of evidence, with regards to the survival of pyre goods, it is difficult to say if individuals who were cremated for longer periods of time were interred with a greater number of pyre goods.

Figure 16

Interestingly, all of the completely cremated bones belonged to the lower limb, with the exception of one humerus sample (Table 5). The differential cremation between upper and lower limbs was statistically significant at the 0.05 level ($X^2 = 4.06$; $p = 0.041$). This creates significant sampling considerations for techniques such as FTIR analysis as it suggests, similar to histological sections, that different results will be achieved from different areas of the body. This is potentially more significant with the use of CI than histological section, as the numerical differences between, for example, burned and unburned archaeological bone, can be slight. The results gained from analysis of the Elsham remains demonstrate that areas with more fat, such as the thighs, were cremated more successfully. This could either be a result of their position on the pyre or the amount of fat stored in these appendages. This is supported by the presence of numerous complete hand phalanges that were recovered relatively unburned from the Elsham burials. The influence of differential burning on skeletal analyses will likely be reduced by the application of a range of techniques on the material in combination with consistent sampling across bodies and studies.

Table 5

4. Discussion

The combined use of histomorphometry and FTIR analysis generally corresponds well with macroscopic examination, though anomalies do occur and demand further explanation. The techniques employed in this paper have demonstrated that the temperatures reached on the funerary pyres at Elsham ranged from 600°C to over 900°C. Based on numerous examples acquired from the Elsham samples it appears that high temperatures were achieved, which is exhibited on the periosteum and outer cortical region of long bones. However, these bones were not completely cremated, suggesting they were burnt for a shorter period of time. This indicates that the duration and oxidising conditions of cremation varied significantly. Holden, Phakey and Clement (1995, 27) illustrated a relationship between the temperature attained in the bone and the distance from the periosteum. Longer periods of time would have allowed complete cremation as the temperature would have been at a relatively constant heat. In contrast, shorter periods of time would have affected the periosteum and outer cortical bone severely but the endosteum and inner cortical bone would not have been completely cremated. It is difficult to say how long the cremation process would have lasted. Duration and oxidation would have depended on many factors such as weather conditions, fuel type, size of the pyre and physique of the deceased. This is exemplified by ethnographic evidence for a pyre in Bali which took two and a half hours with the use of gas jets but would normally have taken all day without the use of such devices (Downes 1999, 23).

Based on the results from the Elsham sample examined in this study, it is suggested that some individuals were cremated for longer periods of time than others. This has led to a number of inferences regarding social status. Rather than basing archaeological understanding on grave goods alone, the techniques used in this article propose an alternative avenue, and this is the investigation of the time and economic investment that was spent on the cremation process. A large funerary pyre may have paralleled contemporary richly furnished inhumation burials with regards to visual experience which evoked memories of the deceased. The greater losses within a community may have resulted in an elevated ability, and perhaps a greater need, to expend resources in a more impressive funerary display. It is possible that the cremation rite of a more prominent member within society took a longer period of time, as the community may have invested larger amounts of fuel, more time in the construction of the pyre and subsequent collection of cremated material. Literary references that support these points come from Tacitus (1999, 50-51) and Beowulf (Porter 2006, 185) which both discuss the collection of certain types of wood for famous men. While in Homer's Iliad (2003, 442) it was noted that Hector, the deceased, was cremated and his brother and comrades collected his white bones. There is a possibility that when the bones turned white it may have been a sign that this was the stage when a body was 'completely' cremated. However, the white colour may only have been revealed on the periosteal region while the internal cortical structure was not destroyed as a result of lower temperatures, deoxidising conditions and a shorter period of time exposed to high temperatures.

Interestingly, all of the completely cremated bones belonged to the lower limb, with the exception of one humerus sample. The differential cremation between upper and lower limbs was proved to be statistically significant. It appears that arm positions were furthest away from the centre of the pyre. For instance, they may have been placed on the cadaver's torso region, and were perhaps also poorly cremated due to the lack of fat on these extremities. However, there are less soft tissues around the radius and ulna so they would be expected to cremate more successfully than the femur, which is surrounded by a greater amount of muscle. At the early Anglo-Saxon inhumation cemetery at Berinsfield in Oxfordshire the female with the highest number of grave goods was buried in a supine position with her arms folded across her stomach. Similarly, the child interred with the greatest number grave goods was laid in a supine position with their arms tightly flexed across her chest (Boyle *et al.* 1995, 117). This may suggest that individuals of a certain social standing were placed on the pyre, or indeed inhumed, in a specific position. However, further research is needed to prove this theory. The results gained from analysis of the Elsham remains demonstrate that areas with more soft tissues, such as the thighs, were cremated more successfully which may have been due to their location on the pyre or the amount of fat in these locations. This is supported by the presence of numerous complete hand phalanges that were recovered relatively unburned from the Elsham burials.

5. Conclusion

Macroscopic examination is useful to gain a general idea of temperature, though more advanced techniques, in the form of thin-section and FTIR analysis are required to gain a more precise temperature range. The combined use of these methods can contribute to our understanding of cremation temperature and duration for osteological material from a variety of contexts. The anomalies that were noted in this study highlighted that duration was variable in the cremation process. However, further work is required to gain a more accurate understanding of the actual cremation duration during the early Anglo-Saxon period. This study also revealed that the temperature of these pyres ranged from 600°C to over 900°C. Although pyre debris, such as glass and copper alloy globules and slag, were noted when assessing the cremated bone further work is required to determine the higher temperatures reached by these cremation pyres which exceeded 900°C. Experimental work would be a good starting point by heating human bone to temperatures of over 900°C and subsequently examining it using the methods employed in this paper. It would also be useful to examine a number of different bones from the same individual to gain a greater understanding of the temperatures attained throughout the whole cadaver and their position on the funerary pyre. Further work in this area, by combining histomorphometry, FTIR analysis and macroscopic examination, will not only contribute to our knowledge of pyre technology and funerary ritual among past communities who practised the cremation rite but will also assist in our understanding of modern cremated material from unknown contexts.

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