A new approach to profiling taphonomic history through bone fracture analysis, with an example application to the Linearbandkeramik site of Ludwinowo 7.

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Abstract:

This paper presents a new method of assessing and displaying taphonomic history through detailed bone fracture analysis. Bone is a particularly useful indicator of taphonomic processes as it is sensitive to *when* it is broken based on degradation over time. Our proposed ‘fracture history profiles’ show the sequences of fracture and fragmentation that have affected assemblages of bone specimens from the death of the animal to recovery by archaeologists. The method provides an assessment of the carcass processing traditions of past people, relating specifically to bone marrow and bone grease extraction. In addition, by analysing post-deposition fracture and bone modifications caused by burning, gnawing and other taphonomic agents, it is possible to reconstruct a comprehensive taphonomic history for each archaeological context. This has implications for understanding effects on other artefacts that have no equivalent diagnostic features for determining timing of breakage, and also for establishing the nature of events such as secondary disturbance of deposits. This method will be demonstrated using a case study from the Neolithic Linearbandkeramik culture.

Highlights:

- A new method of assessing and displaying taphonomic history through detailed bone fracture analysis is presented, called a ‘fracture history profile’.
- The method utilises fracture type based on fracture morphology, alongside taphonomic indicators and fragmentation analysis, to show the sequences of carcass processing and deposition that have affected animal bone specimens.
- The method has implications for understanding taphonomic histories of other artefacts with no comparable diagnostic features.
- The case study shows that fracture history profiles can be used to show differences in consumption and deposition between archaeological contexts.

1.1 Introduction

The importance of taphonomic analysis of archaeological material has long been widely recognised (Behrensmeyer, 1978, Brain, 1983, Lyman, 1994) and its application to zooarchaeology has been the subject of many recent papers (Madgwick, 2014, Madgwick and Mulville, 2012, 2015, Orton, 2012). An integral part of taphonomic analysis is the study of fracture patterns on archaeological animal bone, a practice that has been steadily gaining recognition and utility over the last few decades. Since one of the first truly comprehensive studies by Johnson (1985; see also Morlan, 1984, Villa and Mahieu, 1991) the methodology has been more recently improved upon through actualistic archaeological experiments on modern animal bones (Karr and Outram 2012a, 2012b, 2015) and through new recording methodologies such as the Fracture Freshness Index (Outram 1998, 2001, 2002). These studies have allowed the refined application of bone fracture analysis and paved the way for it to be more accessible, and ultimately, more commonly included in zooarchaeological analyses.

Fracture freshness analysis has in the past been primarily a useful tool in identifying the intensity of bone fat processing practices on a site, namely bone marrow and bone grease extraction (e.g. Karr, et al., 2015, Outram 1999, 2001, 2003). Bone marrow processing involves splitting bones to access the marrow cavity, and can be suggested in the archaeological record through an abundance of long bone shafts that exhibit characteristics of fresh (peri-mortem) fracture (Johnson, 1985: 188). Bone grease processing, a much more labour-, time- and fuel- intensive procedure, involves the comminution and subsequent boiling of cancellous bone such as epiphyses and axial elements (Outram, 2001: 402). It causes a similar fracture pattern in long bone shafts to marrow processing but would also affect cancellous material (*ibid.*). Identifying these processes in the archaeological record can help reconstruct diet over time and potentially indicate times of stress in the population when bone fat was more intensively sought (Outram, 2004).

This paper will show that fracture freshness analysis can also be used to profile taphonomic processes that have affected archaeological contexts through studying the types of fractures found on bones and the order in which they occurred. Bone is a particularly useful tool for profiling taphonomic patterns as it is a material that is sensitive to *when* it is broken depending on degradation over time. When viewed alongside data for levels of butchery, burning, gnawing, weathering stages and stratigraphic indications of re-cutting, bone fracture analysis can provide a full picture of the carcass processing and refuse deposition practices happening on a site. In addition, it can reveal patterns potentially relating to later disturbance of features and secondary deposition.

2.1 Analysing bone fracture

The primary methodology necessary for this analytical technique is the identification of different fracture types on bones using a number of key fracture characteristics. On fresh long bones, dynamic loading causes a helical fracture, characterised by several fracture lines radiating out from a cone of bone displaced beneath the loading point, which may show evidence of a dynamic impact scar (Outram 2005: 33). Fractures spiral around the diaphysis and tend to produce a helical breaks inclined at about 45 degrees to the longitudinal axis (Johnson, 1985: 172), leaving sharp edges against the bone’s cortical surface (Outram, 2002). Dry bone has low moisture content and has a greater tendency to fracture in straight lines or steps following drying micro-cracks with the bone’s structure. The fracture surfaces tend to be perpendicular to the cortical surface and the texture of the fracture tends to be rough (Johnson, 1985: 177, Outram, 2001, 2002). All these features are often present in their full extent in mineralised bones that have lost their energy-absorbing capacity and anelastic capabilities through extensive moisture loss and altered microstructure (Outram, 2001: 403, Johnson, 1985: 178).

Fracture analysis can be carried out using the Fracture Freshness Index, or FFI (Outram, 1998; Outram, 2001). The FFI scores three fracture characteristics (outline, angle and texture) from 0-2, resulting in a combined score out of six. The lower the FFI, the fresher the characteristics displayed by the bone fracture. Scores from 0-2 represent bones broken in a relatively fresh (perimortem) state and a score of 6 represents a bone fractured when dry or mineralised, with no evidence of fresh fracture. Scores of 3, 4 or 5 represent either bones that were broken when becoming fairly dry, likely unfit for marrow extraction, or bones with mixed fracture characteristics (Outram, 2001; 2005). The FFI is extremely useful as an analytical tool to identify the freshness of breakages in assemblages with one number (the mean FFI), however it does not take into account bones where two or more types of fracture are visible. For example, a bone with a fresh fracture that was later fractured again when mineralised will have an FFI score that is the same as a single fracture on a drying bone, leading to a degree of equifinality. Therefore, it is of significant value to also subjectively classify and record the types of fractures found on specimens as “fresh”, “dry” and/or “mineralised”. This data forms the basis of the method presented below.

It is also important to note other taphonomic features on bone specimens, which could explain some of the fracture types found on the site and add to the depth of knowledge about carcass processing and deposition practices. Depending on the research questions, butchery can be recorded in varying degrees of detail. Evidence for types of heat exposure on bones should be noted, as specific cooking practices affect bone diagenesis and fracture properties when broken (Outram, 2002). Indicators of carnivore and rodent gnawing on the bones should also be recorded, as these could also cause fractures on bone both before and after human processing activities (Blumenschine, 1995). Other taphonomic features such as weathering, trampling, staining, root etching, deposit compaction, bioturbation and recovery bias can all cause varying fracture types (Outram, 2001: 403).

2.2 Fracture history profiles

In this section hypothetical data will be employed to illustrate the evolution of the graphical representation of fracture patterns (see figure 1). In the stacked bar charts below colours correspond to the three fracture types; fresh fracture is blue, dry fracture is green and mineralised fracture is yellow. In the fracture history profile darker shades and/or patterns of these colours indicate secondary or tertiary fracture (figure 1, right). The use of patterns in addition to colour shades allows the graph to retain its utility in greyscale. The order of the fractures in the graph reflects the chronological order in which they occur – for example, fresh fractures cannot occur on bone that is already dry or mineralised.

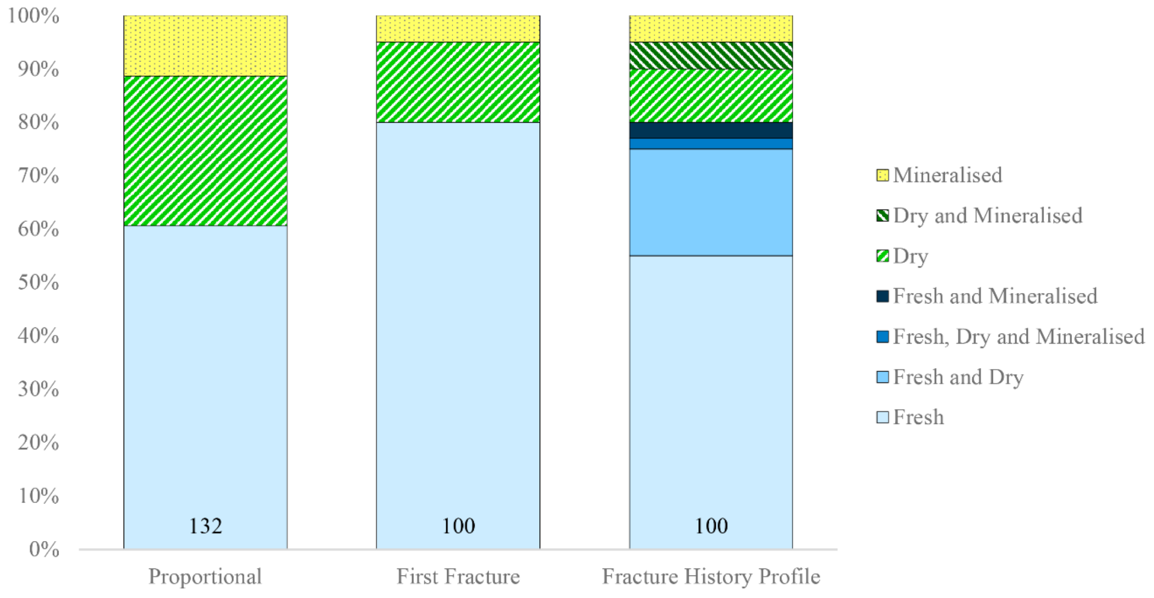

Figure 1: Three methods of displaying fracture analysis on the same constructed data. The number of specimens is displayed at the base of each bar.

One method for presenting fracture information is to represent the proportions of different types of fractures (figure 1, left). This method counts all the fracture types recorded on bone fragments and displays each type of fracture as a percentage of the total number of fractures (see Outram, et al., 2005, Harding, et al., 2007). In this method the total number of observations is the total number of fractures rather than bone specimens, as bones with two different fractures are counted twice. This approach usefully displays the incidence of different fracture types in any particular context and contributes to general taphonomic discussions, including those related to extensive post-depositional disturbance. However, if one wishes to understand the prevalence of fresh bone fracturing, related to activities such as marrow extraction, then high rates of secondary fracture could mask that activity.

To address this specific issue column charts displaying only the first fracture to occur on a specimen can be deployed, as shown in the central chart of figure 1 (Parmenter, 2015, Parmenter, et al., 2015). For example, if a bone was fractured when fresh and then again when mineralised only the fresh fracture would be counted. This method is particularly useful for looking at likelihood of bone marrow and bone grease processing as it removes the masking effects of having more than one fracture per specimen, resulting in the better representation of fresh fracture. However, important taphonomic information about site formation processes related to instances of secondary fracture is lost if using only this type of graph.

Fracture history profiles are the natural evolution of the first two forms of chart. In essence, they display the same information as first fracture graphs in that the number of fractures presented is determined by the first fracture to occur on bones. In addition, however, they also include information about subsequent fractures within the first fracture proportions. In the hypothetical example (figure 1, right), the fracture history profile shows that 80% of bones were first fractured when fresh, of which 31.3% were also fractured secondarily. This method is particularly useful for looking at carcass processing *and* taphonomic differences between contexts and sites. These differences can then be investigated through looking at butchery practices and evidence for burning, gnawing and other taphonomic agents. This new approach to the graphical representation of fracture sequences is by far the most powerful in terms of identifying specific bone processing activities whilst also preserving all the details of taphonomic history reflecting complex site formation processes.

3.1 Materials and methods

The above method of displaying fracture freshness analysis will now be applied to an archaeological case study of the Neolithic Linearbandkeramik (LBK) settlement of Ludwinowo 7, located on the edge of a small elongated plateau in the Kuyavia region of central Poland (Pyzel, 2012: 160). The earliest traces of occupation on the site date to Kuyavian phase I, the late *älteste* LBK, with the main inhabitation of the site in the Kuyavian phase IIA (the Notenkopf) until Kuyavian phase III (*ibid.* 163). The site will be used to demonstrate the instances in which fracture history profiles can be particularly beneficial to archaeological interpretation.

A large sample of the faunal assemblage was analysed by E. Johnson during the NeoMilk project, as part of a suit of analytical techniques used to chronical, map and correlate patterns of environmental and cultural change related to animal management and milk use. Contexts were selected for analysis based on LBK phase, context type and number of specimens. Eight of these contexts or context groups were analysed in their entirety and are compared in this paper, comprising 79.4% of the overall assemblage sample. They include pits, clay pits, and the pit contexts associated with four LBK longhouses (table 1). LBK houses are typically rectangular, timber-framed wattle-and-daub structures, archaeologically visible as horizontal rows of postholes flanked by long pits, or *Längsgruben*, referred to as house pits in table 1 (Bánffy, 2013: 119).

Table 1: List of contexts analysed in full from Ludwinowo 7. Identifiable material includes specimens partially identifiable to species and element type, primarily large/medium mammal long bone shaft fragments.

Context	Type	Contexts	LBK Phase	Identifiable	Indeterminate
Ludwinowo 7 (LDW)	Site	Sample	-	2568	10861
H15	House pits	H42, H48	IIB	262	2353
H18	House pits	A49, A281, A282	IIB	144	421
H22	House pits	F6, F16, F40	IIB	313	1181
H8	House pits	C115, C156	III	259	2214
B156	Pit	B156	III	90	237
G64	Pit	G64	III	115	361
K66	Clay pit	K66	III	263	927
K82	Clay pit	K82	III	132	816

3.2 Methodology

In addition to collecting basic zooarchaeological data such as species and element, analysis of fracture and fragmentation was also undertaken. Fracture morphology was recorded using the FFI and by subjectively noting the fracture types (fresh, dry and/or mineralised) present on all fractured marrow-bearing bone fragments larger than 30mm in maximum dimension. Material from all species (including those specimens identified to "large/medium mammal") was included in this analysis. Fragmentation was analysed by weighing each bone and assigning it to a size class based on maximum dimension, with bones of all size classes contributing to taphonomic and fragmentation analysis. Evidence of butchery marks, burning and gnawing were recorded by type on identifiable material and by frequency of specimens affected per context for indeterminate material. Other taphonomic instances such as evidence of weathering, root etching and erosion were only recorded on identifiable material.

4.1 Results

The Ludwinowo 7 assemblage was dominated by domestic cattle (*Bos taurus*) at 74.7% of the number of identifiable specimens (NISP), with small stock (sheep [*Ovis aries*], goat [*Capra hircus*] and pig [*Sus scrofa domesticus*]) represented in relatively low numbers (14.6% NISP). Wild animals including aurochs (*Bos primigenius*), wild horse (*Equus ferus*), red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) contributed to 9.1% of the NISP. A complete zooarchaeological report of the faunal material from Ludwinowo 7, with a higher-resolution analysis of species, was undertaken by Osypińska (2011).

4.1.1 Bone fat processing

The use of fracture history profiles alongside other analytical techniques builds a picture of carcass processing and depositional practices at Ludwinowo 7. The fracture freshness analysis indicates that marrow was processed on site, as 44% of marrow bearing bones of all species were broken when still fresh (figure 2). However, alongside the mean FFI of 3.6, this indicates that bone was not fractured when fresh in all instances. Fresh fracture was more common on marrow-rich elements (the humerus, radius, femur and tibia) than elements with low marrow yield (the mandible and metapodia; see figure 2). This analysis of fracture suggests that marrow rich bones were being preferentially targeted, but that many marrow-bearing bones were left unbroken until the bone had degraded to an extent where the marrow may no longer have been edible.

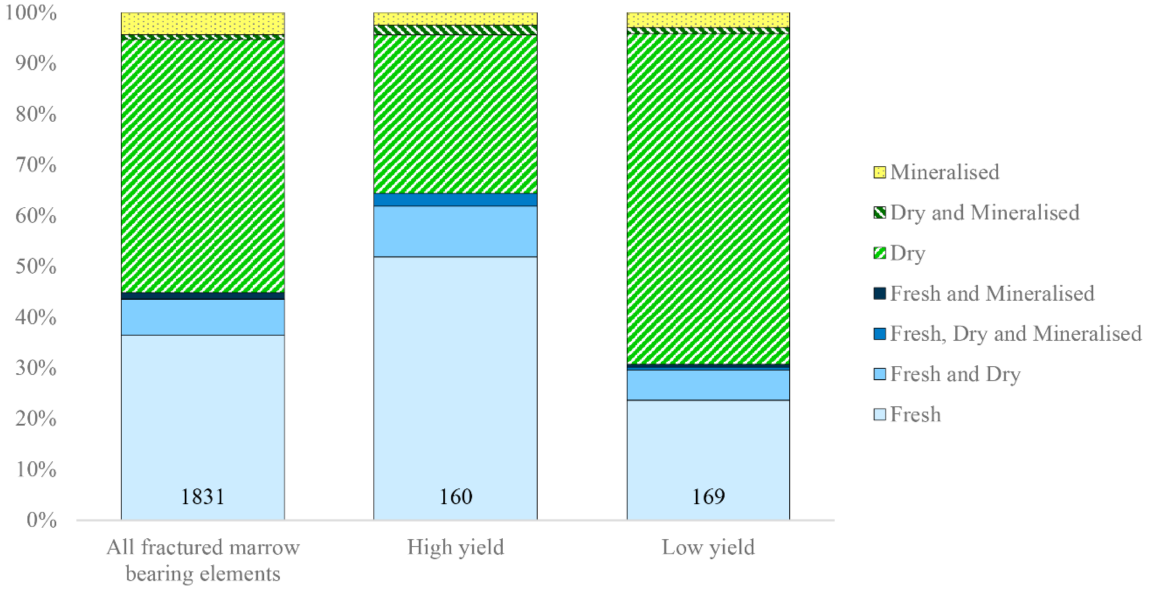

Figure 2: Fracture history profiles showing the proportions of different fracture sequences affecting all fractured marrow-bearing elements from Ludwinowo 7 (left) and on high (humerus, femur, radius and tibia; centre) and low marrow yield elements (mandible and metapodia; right) from Ludwinowo 7.

The fragmentation analysis similarly does not suggest intensive bone grease processing. Comminution of cancellous elements was not systematic, as a low proportion of the overall assemblage weight (15.4%) was represented by fragmented specimens <40mm in maximum dimensions and many epiphyses suitable for grease extraction were unfragmented. In archaeological contexts showing clear bone fat exploitation the percentage of freshly fractured bones is usually very high, in addition to high levels of comminution of cancellous elements contributing to a large proportion of the assemblage weight in small size classes (for a good example, see Mitchell, South Dakota (Karr, et al., 2015)). This level of bone fat processing is not in evidence in Ludwinowo 7.

The moderate intensity of bone fat processing could be directly related to the intensity of dairying on the site. This is suggested to be relatively high by the cattle-dominated faunal assemblage (see also Osypińska 2011), an intensification of cattle herd management towards a dairy economy over time (Gillis, pers. comm.) and evidence for cheese making found in LBK sieves (Salque, et al., 2015).

4.1.2 Taphonomy and secondary fracture

The fracture history profile for the overall assemblage shows that 9.4% of fractured specimens were fractured more than once. In particular, 16% of freshly fractured bone was fractured again when dry. A context that displays the benefits of using fracture history profiles to show subsequent fracture is House 18, which showed 42.3% of freshly fractured bones were subsequently fractured when dry or mineralised. In figure 3 below, the fracture freshness data is arranged in the same manner as the constructed data in figure 1. It shows that this secondary fracture masks some primary fracture in the proportion graph, and the first fracture graph discounts secondary fracture. The fracture history profile shows all of this information at its most complete. This example also highlights how the fracture history profile can be used to clarify mean FFI scores. House 18 has a mean FFI of 3.8 that suggests more dry fracture than, for example, House 22 (mean FFI 3.3). In fact, the fracture history profiles show they had very similar percentages of fresh fracture (H18 49.5%, H22 49.8%, figure 5 and 6), with the higher mean FFI likely the result of subsequent drier fracture. Without the fracture history profile, the mean Fracture Freshness Index could be interpreted ambiguously.

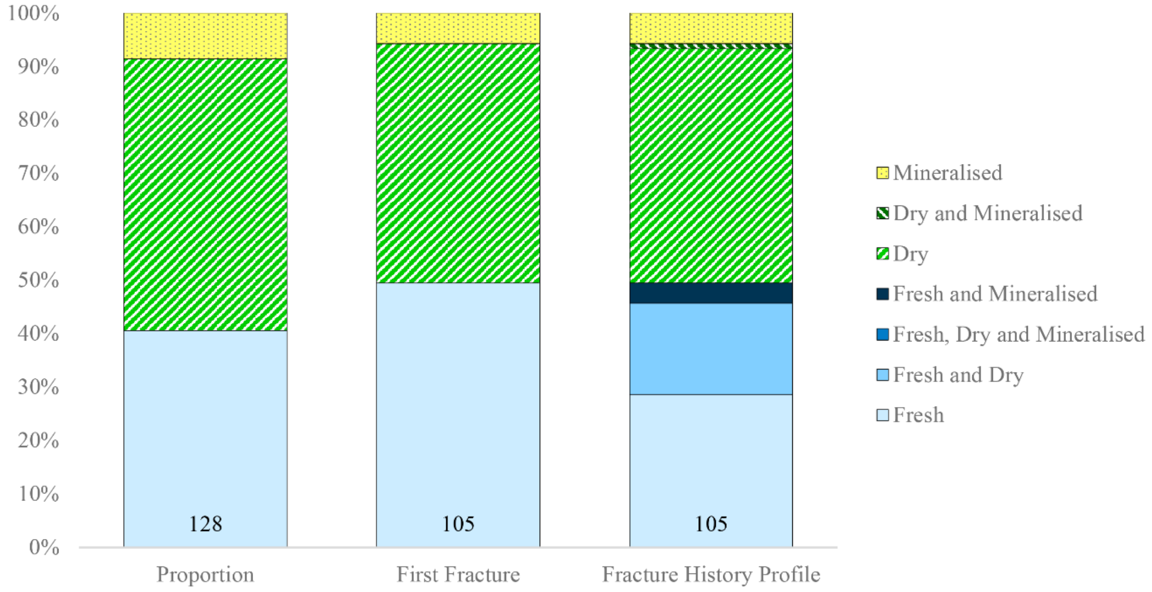

Figure 3: Three methods of displaying fracture analysis using data from House 18.

Many processes can contribute to secondary fracture such as heat exposure, carnivore gnawing, trampling, compression or disturbance once buried. Of these processes the evidence for varying degrees of burning, especially roasting, was the most prolific (as shown in figure 4), affecting 31.5% of the identifiable sampled assemblage. 45% of bones that had evidence for secondary fracture showed evidence of some form of burning, although evidence of heat exposure was also present on 38% of bones that only had fresh fracture. Outram's (2002: 56-57) experiments on fracture freshness showed that bones heated in an oven between 80-100 degrees for one hour still showed evidence of fresh fracture characteristics. This could indicate that bones were heated for long enough to leave evidence of heat exposure but retain some fresh fracture characteristics. Roasting of cattle bones before marrow extraction has been previously suggested for the early farmers of the North European Plain by Marciniak (2008, 102). Perhaps these bones were more susceptible to subsequent fracture due to their advanced drying.

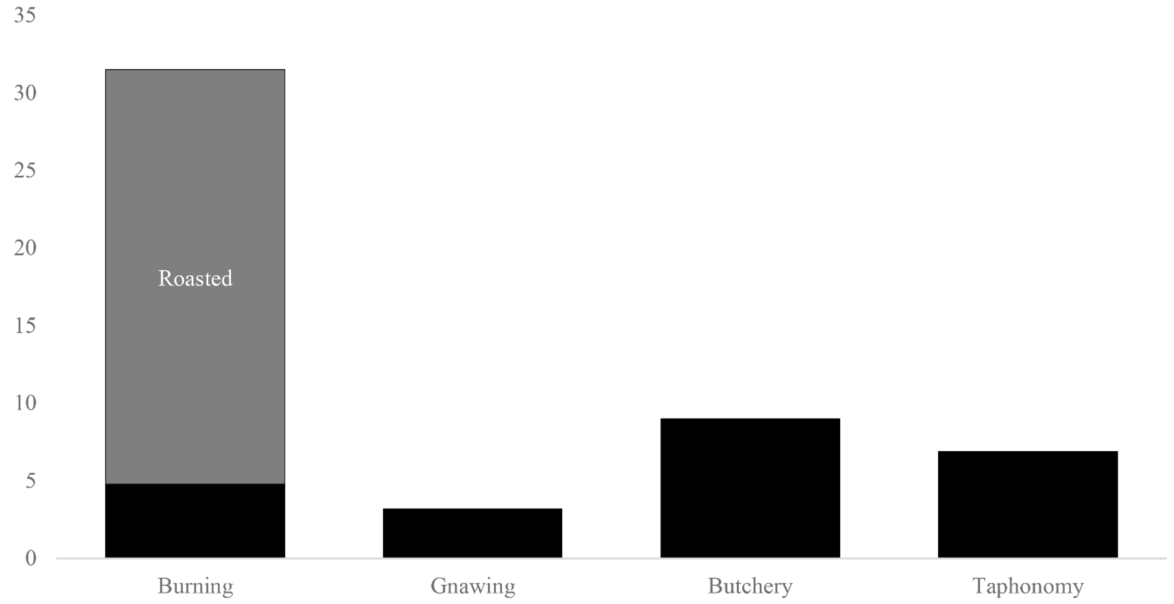

Figure 4: Percentages of identifiable bones from Ludwinowo 7 (n = 2568) affected by bone modifications.

4.2 Intra-site comparisons

Ludwinowo 7 is a particularly useful case study for this methodology as the fracture freshness and taphonomic analysis show different patterns of carcass processing and deposition between contexts. In figures 5-8, the house pit contexts from phases IIB (15, 18, 22) and III (8) are on the left, followed by unassociated pits B156 and G64, and clay pits K66 and K82, all phase III. The sample size is at the base of each bar.

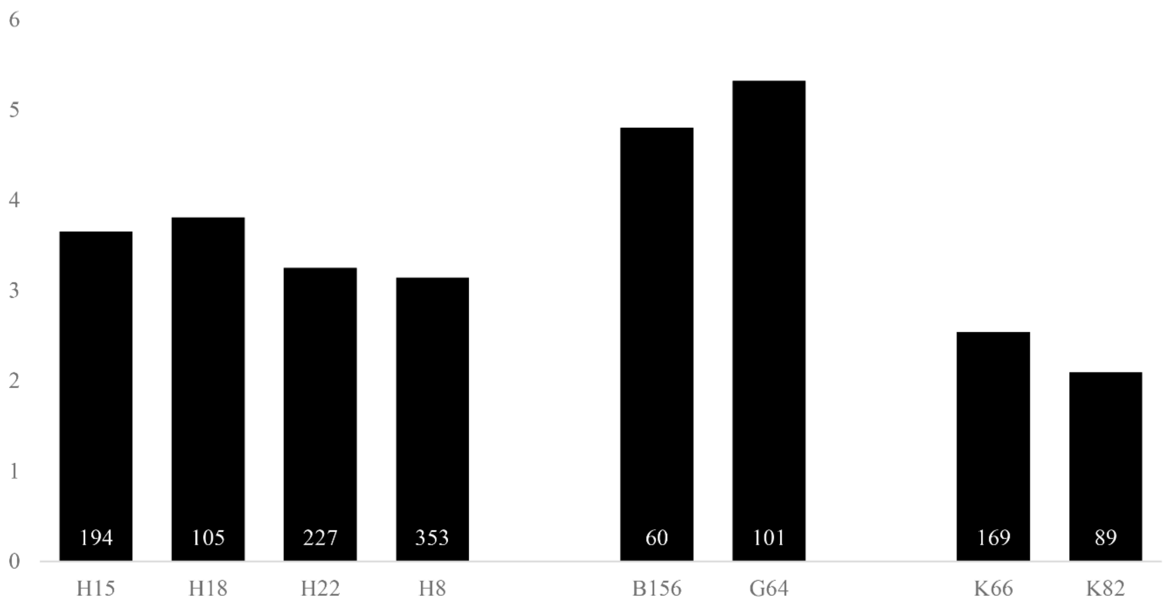

Figure 5: Mean Fracture Freshness Index out of 6 for the compared contexts. A high FFI score indicates an assemblage with more fractures on drying, dry and mineralised bone.

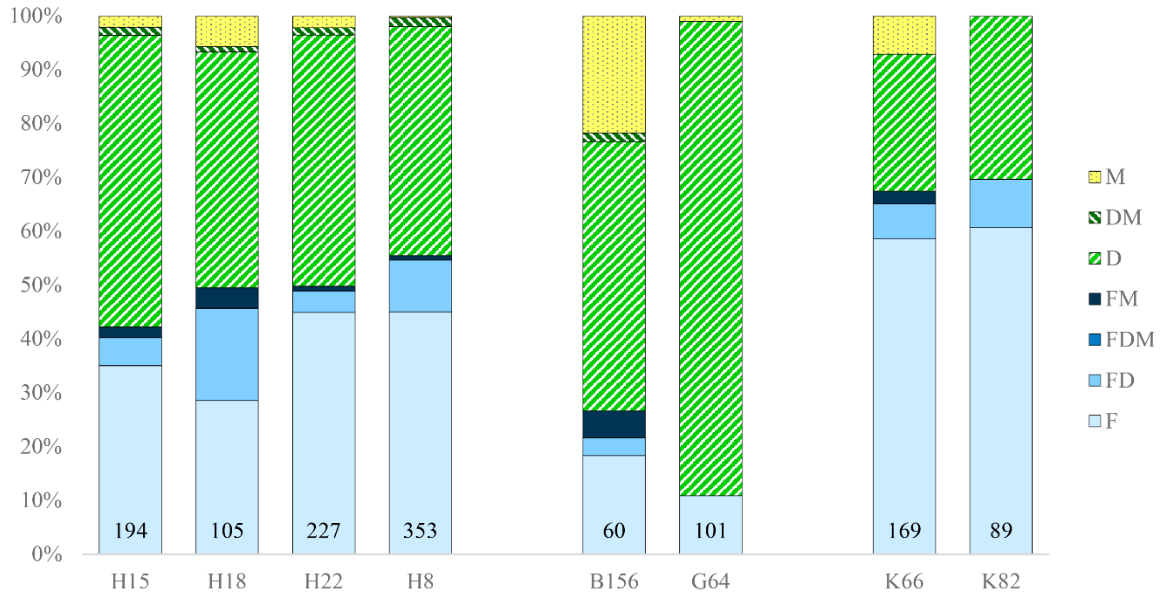

Figure 6: Fracture history profiles of the compared contexts in Ludwinowo 7. F = Fresh, D = Dry and M = Mineralised, and combinations thereof.

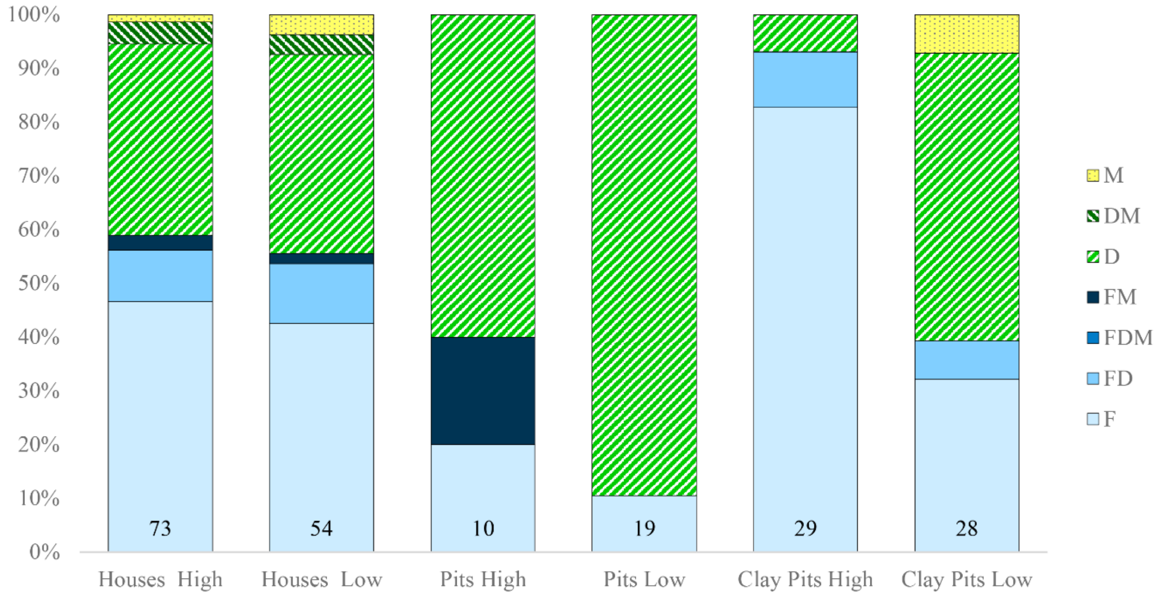

Figure 7: Fracture history profiles of high (humerus, radius, femur, tibia) and low (mandible, metapodia) yield marrow-bearing bones from all species within contexts of the same type. Small sample sizes necessitated the combining of the contexts into house pits (H15, H18, H22, H8), pits (B156, G64) and clay pits (K66, K82).

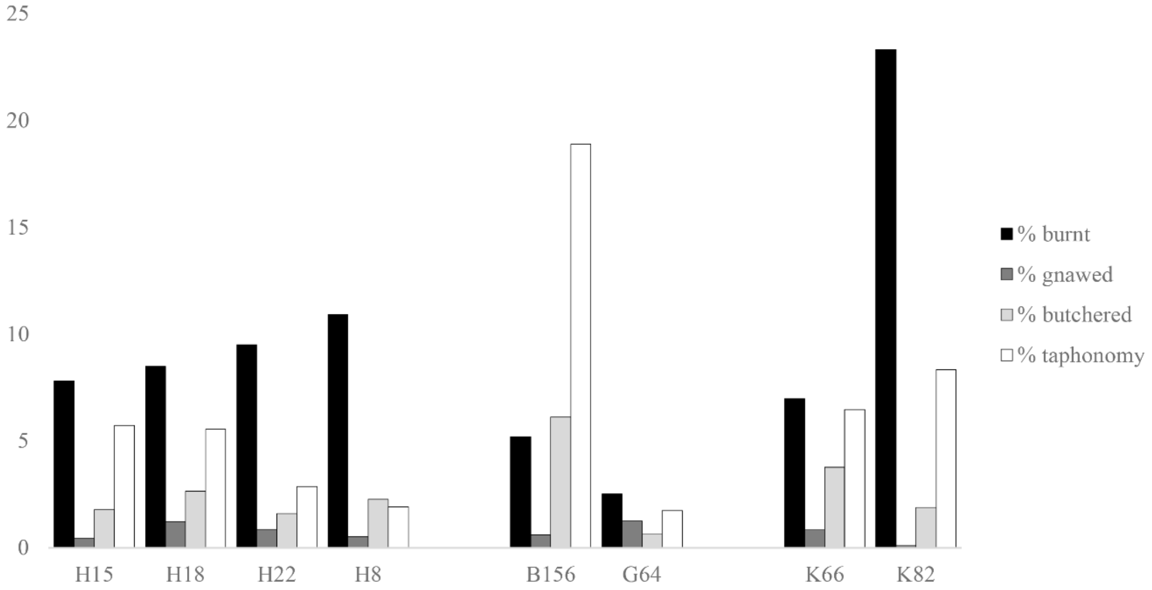

Figure 8: Percentage of all bones (identifiable and indeterminate) with evidence of burning, gnawing and butchery and percentage of identifiable bones affected by taphonomy per context.

The house pits showed a fairly consistent level of fresh fracture (figures 5, 6), burning and taphonomy. There was some secondary fracture notable in the house pits, more common in some houses than others, especially House 18 as mentioned above (figure 3, see also figure 9). House pits had typically higher proportions of high-yield marrow bearing elements, particularly the humerus and tibia, to low-yield marrow bearing elements (n = 73/54). Interestingly, the amount of fresh fracture on high and low yield bones was less varied for the house contexts as opposed to other contexts (see figure 7). This could indicate that bones were chosen for marrow extraction based on what was nearby at the time, rather than making a specific choice of element. Whilst one has to be cautious assigning pits to individual houses in the LBK, these *Längsgruben* that were clearly amongst the dwellings of the settlement could contain domestic refuse (see Bánffy, 2013, Bickle, 2013).

The two isolated pits (B156 and G64) were not as obviously comparable as the house pits despite being of the same phase. These contexts showed similarly low levels of fresh fracture, although pit B156 also shows a high proportion of mineralised and secondary mineralised fracture (figure 6). This could suggest that the pit was recut and disturbed after the organic content of the bone had been lost. These contexts showed higher levels of fracture on high yield elements than low yield elements, although the percentage of fresh fracture was much lower than the house and clay pits. The isolated pits had a higher proportion of low yield elements than high yield elements compared to the other context types, particularly in B156 where there were many indeterminate mandible fragments (n = 10/19; see figure 7). There were also differences in the taphonomic modifications between the contexts, with B156 showing high levels of butchery, burning and especially erosion compared to G64 (figure 8), which could be an indicator of secondary deposition. The likely interpretation for these contexts is that they were isolated depositions that were unrelated to each other and potentially other context types.

The clay pits present obvious differences to the two other contexts types. These two objects are parts of a pit complex from the same area and time period (phase III) although they do not directly abut. They both have high levels of fresh fracture (figures 5, 6) and a high disparity in the amount of fresh fracture between high and low yield elements, which were fairly equally represented in the clay pits (n = 29/28; figure 7). Fragments of humerus, radius and tibia were fractured freshly in 90% of cases in the clay pits. Marciniak notes that clay pits likely had special functions related to the consumption of cattle (2008: 102), which was significantly better represented in these contexts than the combined house contexts (87.3% NISP in the clay pits compared to 71.5% in the house pits; $p=<0.001$). Cattle were commonly fractured freshly in the Ludwinowo (52.2%) but were affected by a significantly higher proportion of fresh fracture in the clay pits (70.6%, $p=0.0182$). Despite their similarities there was a statistically significant ($p=<0.001$) difference between the two contexts in the level of burning, with 23% of the assemblage from K82 burnt and K66 under 10% (figure 8).

4.2.1 Correspondence analysis

Figure 9 uses correspondence analysis to show the association between different archaeological features based on their fracture histories. For each context the percentage of all fractured marrow-bearing bones affected by each sequence of fracture was calculated. This is the same data as displayed by the fracture history profiles in figure 6. The resulting correspondence analysis (figure 9) highlights the contextual groupings, with the house pits clustered in the centre of the graph showing association with fresh and dry fracture. House 18 shows more association with secondary dry and mineralised fracture, which is to be expected based on the individual fracture history profile (figure 3; figure 6). The clay pits (K66 and K82) associate with each other and with fresh fracture, whereas the isolated pits B156 and G64 do not group with each other or with any other contexts, which corroborates the suggestion of different depositional histories between these contexts.

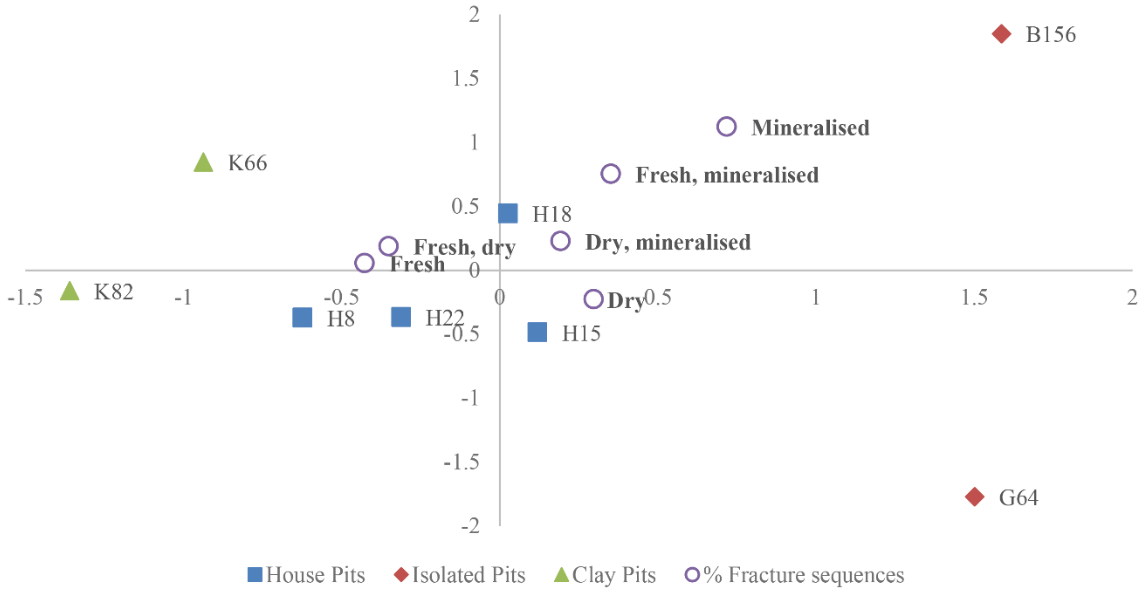

Figure 9: Correspondence Analysis (using Past3) of the percentage of fractured bones per context affected by different fracture sequences.

5.1 Conclusion

In conclusion, this paper has shown that fracture history profiles provide a wealth of data about archaeological assemblages. They can help elucidate the function of certain contexts through establishing carcass processing patterns related to activities such as bone marrow and grease extraction. In addition, they help highlight levels of later damage to bones that could indicate post depositional disturbance, caused by activities such as recutting of features and intrusions by burrowing animals. This method is especially useful when combined with a range of other taphonomic data such as to allow the reconstruction of a bone specimen's journey from animal to zooarchaeologist. This approach lends itself to both intra- and inter-site comparisons through multivariate analysis of contexts and phases.

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