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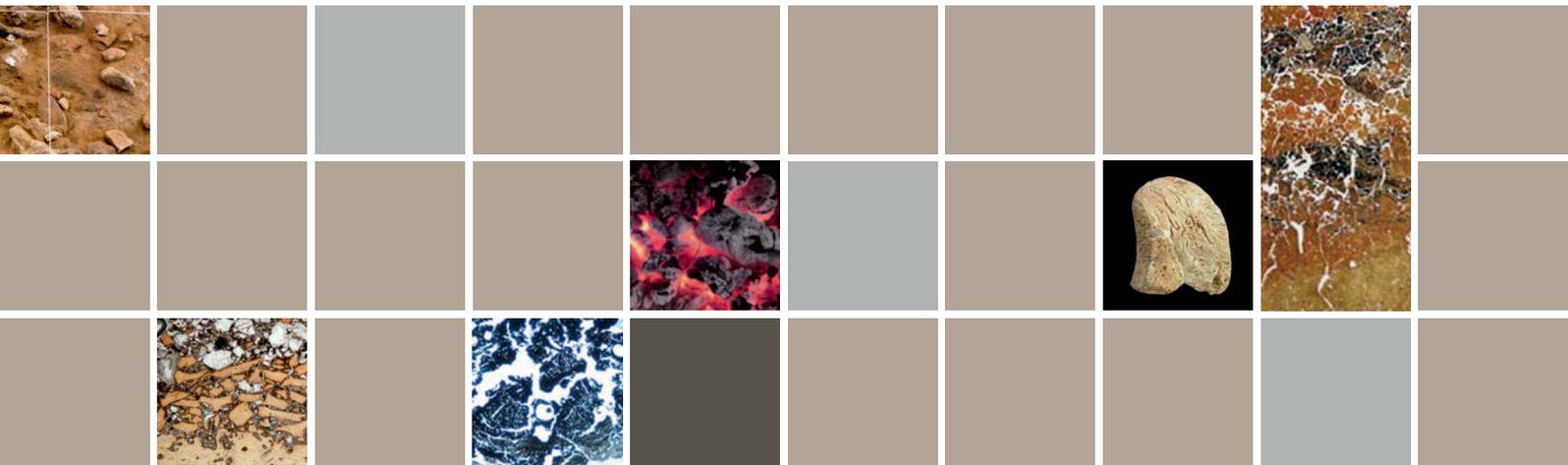
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**THE TAPHONOMY OF BURNED ORGANIC RESIDUES AND  
COMBUSTION FEATURES IN ARCHAEOLOGICAL CONTEXTS**



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# TAPHONOMIC IMPLICATIONS OF THE USE OF BONE AS FUEL

Eugène MORIN

## Abstract

This paper explores the effects of the use of bone as fuel on archaeological skeletal part representation. Faunal data from the Paleolithic site of Saint-Césaire show that this activity may present an archaeological signature similar to that of differential preservation. The bones most frequently burned at Saint-Césaire are also those that are the least dense and that contain the most grease. The analysis of faunal remains from Saint-Césaire also suggests that spongy bone fragments from small-bodied and large-bodied taxa are subject to differential identification.

**Keywords :** archaeology, fauna, burning, burned bone, bone identification

## Introduction

Despite some early innovative research, particularly the work of Brain (1969), taphonomic analysis of faunal assemblages did not become common practice in archaeology until the end of the 1970s. Since that time, taphonomic studies have highlighted the difficulties related to the interpretation of anatomical profiles (Binford & Bertram, 1977; Binford, 1978, 1981; Poplin, 1978; Lyman, 1984; Grayson, 1989; Marean & Kim, 1998; Bartram & Marean, 1999; Outram, 2001; Pickering *et al.*, 2003; Lam & Pearson, 2005; Novacosky & Popkin, 2005; Faith *et al.*, 2007). The consensus that has emerged from these studies is that numerous geological, biological, and cultural factors contribute to faunal assemblage variability. Among the causes proposed to explain this variability, differential preservation generally plays a central role.

The analysis of differential preservation, which is defined as the selective destruction of faunal remains by meteorological and postdepositional phenomena, has greatly evolved over the years. Today, methods relying on quantitative techniques have replaced the subjective evaluations carried out in the past. The latter approaches have, among others, highlighted problems of equifinality in the identification of differential preservation in archaeological contexts (Grayson, 1989). However, the intentional use of bone as fuel has largely been ignored in these discussions, despite the fact that burning may entail the destruction of bone portions or even entire elements. In this article, the factors regulating the selection of bone elements for combustion will be examined, as well as the consequences of this practice for the interpretation of anatomical profiles.

## Density and differential preservation

Bone density is a determining factor in the preservation of faunal remains (Lam & Pearson, 2005). But what is really meant by the term ‘bone density’? Living bone is a solid composite material composed of an organic part dominated by a protein, collagen, and of a mineral part consisting of hydroxyapatite crystals (Boskey, 2006).

The first component lends flexibility to the bone, while the second provides rigidity (Seeman, 2006). According to Boskey (2006), the general characteristics of bone differ little between spongy and compact bone, as both types of bone structure are composed of a solid mineral matrix composed of small canals, spaces (*lacunae*), and bone cells. The difference between compact and spongy bone lies in the organization of the bony matrix: spongy bone is composed of thin interconnected spicules, while compact bone is organized in Haversian systems (Boskey, 2006). This structural variability results in differences in “bulk density” (Lyman, 1994), or more exactly, differences in bone porosity, a term that more accurately captures the structural changes encountered within a single bone. A bone with low bulk density is therefore porous, and these pores are generally filled with grease (Brink, 1997). The presence of a large number of pores increases the surface area to volume ratio of the bone, which may contribute to the *post mortem* fragility of bone. In archaeological contexts, the rarity or absence of spongy bone may be indicative of differential preservation of elements.

However, there are factors besides differential preservation that may modify anatomical profiles as a function of bone density. These factors include the destruction of spongy bone by carnivores (e.g. Binford, 1981; Blumenschine, 1986; Munson, 2000), the production of bone grease (Brink, 1997; Munro & Bar-Oz, 2005), and a practice that is becoming rare—selective discard during archaeological excavation, generally carried out at the expense of long bone diaphyses (Turner, 1989; Marean & Kim, 1998; Grayson & Delpech, 2008). With the exception of selective discard, which decreases correlations with density, these factors are important because their anatomical signatures may be very similar to those of differential preservation. Is this also the case for intentional burning?

## The relationship between bone porosity and combustibility

A growing number of studies suggest a non-random use of bone as fuel during the Late Pleistocene in France (Castel, 1999; Costamagno, 1999; Costamagno *et al.*,



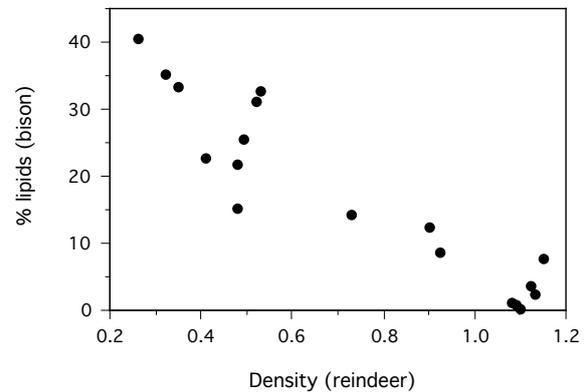
1999, 2005; Morin, 2004; Villa *et al.*, 2004; Théry-Parisot *et al.*, 2005). Is it possible to reconstruct the decision-making process regulating the selection of bones for burning during the Paleolithic? If yes, can we determine if these decisions were mediated by bone porosity? An examination of the relationship between bone porosity and combustibility permits a response to these questions.

If certain parameters (e.g., degree of fragmentation, age and condition of the animal, humidity level) are held constant, the combustibility of bone should be correlated with the quantity of lipids the bone contains, as lipid molecules are highly flammable. Experimental data support this hypothesis and show that spongy epiphyses generally burn much better than compact diaphyses (Costamagno *et al.*, 1999, 2005). However, it remains unclear whether this general relationship holds true when examined in detail. Is bone porosity in fact a good indicator of grease content?

In order to address this problem, the density of reindeer bones (*Rangifer tarandus*, Lam *et al.*, 1999) was compared with the percentage of lipids in bison bones (*Bison bison*, Brink, 1997; Emerson, 1990). The use of two different species in this comparison, which was necessary due to a lack of data, limits the scope of the results obtained here. Nevertheless, given that bone porosity seems to vary little between artiodactyl species (Lam *et al.*, 1999), it is not unreasonable to suggest that the skeletal fat content of reindeer and bison varies in similar ways.

Figure 1 shows a very strong negative correlation between reindeer long bone density and the percentage of fat in bison long bones (Spearman's  $\rho = -0.87$ ,  $p < 0.001$ ). The correlation decreases, but remains high, when the carpals, tarsals, and scapula are included (Spearman's  $\rho = -0.60$ ,  $p < 0.01$ ; Emerson 1990: 390, table 5.39, mass in grams, average of four individuals, phalanges excluded, see above for this exclusion; long bone values as calculated by Emerson). This weaker correlation can probably be explained by the absence of diaphyses in Emerson's analysis. It appears that among artiodactyls, bone

density is largely correlated with fat content, but it remains to be seen if porosity can be used to predict the use of bone as fuel in archaeological contexts.



**Fig. 1** - Relationship between the average percentage of fat in the long bones of three plains bison (Brink, 1997: 262, Table 1) and the average density of bones from four reindeer (Lam *et al.*, 1999: 351-353, Table 1).

#### Archaeological application: The case of Saint-Césaire

Located a few kilometers from the village of Saintes in Charente-Maritime, Saint-Césaire is an important site containing an archaeological sequence chronologically spanning the end of the Mousterian through the Evolved Aurignacian (Lévêque *et al.*, 1993). This sequence also contains a Châtelperronian occupation (Tab. 1). Reindeer, bison, and horse are the best represented species in the Mousterian and Châtelperronian levels, while reindeer alone dominate the Aurignacian layers. The site lends itself well to the study of human behaviors, given that the impact of carnivores on the faunal assemblages is minimal (Morin, 2004, 2008). Burned remains are abundant in the Saint-Césaire sequence, representing over 21% of the remains studied, excluding the low density layer EJO inf (Morin, 2004). As at many archaeological sites, the high degree of fragmentation of burned remains made the identification of burned specimens very difficult. As a result, these remains were rarely identified taxonomically. However, burned specimens constitute a relatively large portion of the Early Aurignacian assemblage (EJF, NISP = 4102), a rich layer in which 82% of identified remains, of which 3% are burned,



| Level    | Cultural attribution              | TL dates<br>(in 1000s of years) | Fauna                         |
|----------|-----------------------------------|---------------------------------|-------------------------------|
| EJJ      | Evolved Aurignacian               |                                 | Dominated by reindeer         |
| EJM      | Evolved Aurignacian               |                                 | Dominated by reindeer         |
| EJF      | Early Aurignacian                 |                                 | Dominated by reindeer         |
| EJO sup  | Proto-Aurignacian                 | 30,8-34,0                       | Dominated by reindeer         |
| EJO inf  | Low density                       |                                 | Mixed: reindeer, bison, horse |
| EJOP sup | Châtelperronian                   | 33,7-38,2                       | Mixed: reindeer, bison, horse |
| EJOP inf | Mousterian                        |                                 | Mixed: reindeer, bison, horse |
| EGPF     | Denticulate Mousterian            | 33,5-47,1                       | Mixed: reindeer, bison, horse |
| EGP      | Denticulate Mousterian            | 36,8-39,7                       | To be determined              |
| EGF      | Denticulate Mousterian            | 42,4 ± 4,3                      | To be determined              |
| EGC sup  | Mousterian                        |                                 | To be determined              |
| EGC      | Mousterian of Acheulean Tradition |                                 | To be determined              |
| EGC inf  | Mousterian                        |                                 | To be determined              |
| EGB sup  | Mousterian of Acheulean Tradition |                                 | To be determined              |
| EGB inf  | Unknown                           |                                 | To be determined              |

**Tab. 1** - The Saint-Césaire sequence. Thermoluminescence dates from Mercier *et al.*, 1991. For levels where several dates are available, only the spread of dates is indicated.

are attributed to reindeer. Faunal remains from the Early Aurignacian layer also show systematic fracturing of long bones for marrow extraction.

Reindeer remains from EJF are characterized by significant variations in the frequency of burning of different skeletal parts (Tab. 2). The percentages of burned remains are particularly high among the vertebrae, pelvis, long bone extremities, carpals and tarsals. The degree of carbonization of the remains (Fig. 2) is not consistent with superficial burning during cooking or roasting of fleshed elements (Speth & Clark, 2006). This observation raises the question of whether the pattern of burning in the EJF assemblage is concordant with an intentional combustion of fat-rich, and, hence, highly porous bones.

The question of whether highly porous bones were intentionally used as fuel can be examined by looking at the relationship between the density of skeletal parts and the frequency with which they are burned. In order to avoid the biasing effects of small sample sizes, bone elements or bone portions with a frequency of less than five identified specimens were eliminated from the analysis. Because the Nunamiut avoided burning phalanges, due to the unpleasant odor these elements produce during combustion (Binford, 1978: 153), correlations were calculated twice, once including and once excluding phalanges. The exclusion of phalanges from the sample tends to increase the strength of the correlations, but does not modify the significance of the results.

In the Early Aurignacian layer of Saint-Césaire, the least dense bones of reindeer are the most often burned. The correlation between these variables is strong, negative, and statistically significant, regardless of whether phalanges are included (Spearman's rho,  $r_s = -0.52$ ,  $p = <0.01$ ) or not ( $r_s = -0.61$ ,  $p = <0.01$ ). When the minimum sample size is increased from five to ten specimens, the correlations are strengthened ( $r_s = -0.73$ ,  $p = <0.01$  with phalanges,  $r_s = -0.61$ ,  $p = <0.01$  phalanges excluded). These results

demonstrate that combustion is strongly correlated with bone density in this level, particularly for larger samples

| Anatomic element              | Density | Burned (n)          | Total (n)            | %burned     |
|-------------------------------|---------|---------------------|----------------------|-------------|
| vertebrae <sup>a</sup>        | 0,44    | 39 (8) <sup>b</sup> | 73 (26) <sup>b</sup> | 53,4 (30,8) |
| ribs (RI3)                    | 0,96    | 9                   | 427                  | 2,1         |
| scapula (SP1)                 | 1,01    | 0                   | 20                   | 0,0         |
| humerus P (HU1)               | 0,26    | 0                   | 1                    | 0,0         |
| humerus SH (HU3)              | 1,12    | 1                   | 102                  | 1,0         |
| humerus D (HU5)               | 0,48    | 5                   | 5                    | 100,0       |
| radius P (RA1)                | 0,53    | 14                  | 29                   | 48,3        |
| radius SH (RA3)               | 1,09    | 1                   | 205                  | 0,5         |
| radius D (RA5)                | 0,49    | 1                   | 4                    | 25,0        |
| ulna P (UL1)                  | 0,49    | 2                   | 3                    | 66,7        |
| ulna SH (UL2)                 | 0,84    | 4                   | 31                   | 12,9        |
| scaphoid (scaphoid)           | 0,70    | 2                   | 9                    | 22,2        |
| lunatum (lunate)              | 0,67    | 1                   | 8                    | 12,5        |
| capitatum (magnum)            | 0,69    | 0                   | 7                    | 0,0         |
| unciform (UNC)                | 0,72    | 0                   | 1                    | 0,0         |
| metacarpal P (MC1)            | 0,92    | 0                   | 16                   | 0,0         |
| metacarpal SH (MC3)           | 1,10    | 0                   | 102                  | 0,0         |
| metacarpal D (MC5)            | 0,48    | 0                   | 7                    | 0,0         |
| pelvis (AC1)                  | 0,64    | 10                  | 23                   | 43,5        |
| femur P (FE2)                 | 0,52    | 4                   | 10                   | 40,0        |
| femur SH (FE4)                | 1,15    | 1                   | 93                   | 1,1         |
| femur D (FE6)                 | 0,32    | 4                   | 11                   | 36,4        |
| patella (PA1)                 | 0,57    | 1                   | 6                    | 16,7        |
| tibia P (TI1)                 | 0,35    | 8                   | 11                   | 72,7        |
| tibia SH (TI3)                | 1,13    | 11                  | 373                  | 2,9         |
| tibia D (TI5)                 | 0,73    | 3                   | 8                    | 37,5        |
| malleolar (fibula)            | 0,68    | 4                   | 5                    | 80,0        |
| talus (AS1)                   | 0,68    | 12                  | 18                   | 66,7        |
| calcaneus (CA2)               | 0,94    | 5                   | 11                   | 45,5        |
| cubo-navicular (NC1)          | 0,56    | 5                   | 8                    | 62,5        |
| greater cuneiform (cuneiform) | 0,71    | 1                   | 3                    | 33,3        |
| metatarsal P (MR1)            | 0,90    | 1                   | 32                   | 3,1         |
| metatarsal SH (MR3)           | 1,08    | 9                   | 806                  | 1,1         |
| metatarsal D (MR5)            | 0,41    | 0                   | 3                    | 0,0         |
| phalanx 1 (P1-2)              | 0,92    | 1                   | 40                   | 2,5         |
| phalanx 2 (P2-2)              | 0,72    | 2                   | 23                   | 8,7         |
| phalanx 3 (P3-1)              | 0,48    | 0                   | 12                   | 0,0         |
| Total/Percentage              | -       | 161 (130)           | 2546 (2499)          | 6,3 (5,2)   |

<sup>a</sup>For vertebrae, counts include remains attributed to the same body size class as reindeer but not identified to the species level, in order to compensate for the poor identifiability of this part of the skeleton.

<sup>b</sup>Numbers in parentheses indicate the number of fragments confidently assigned to reindeer.

Abbreviations : P = proximal, SH = diaphysis, D = distal.

**Tab. 2** - Density and percentage of burned reindeer bones in the Early Aurignacian level at Saint-Césaire. Density values are from Lam *et al.* (1999: 352-353, Table 1). The density scan sites are identified in the first column. The density of vertebrae corresponds to the average of the following scan sites: AT1, AX2, CE1, TH1, LU1. Elements for which density values are not available, as well as cranial elements, are not included in the table.



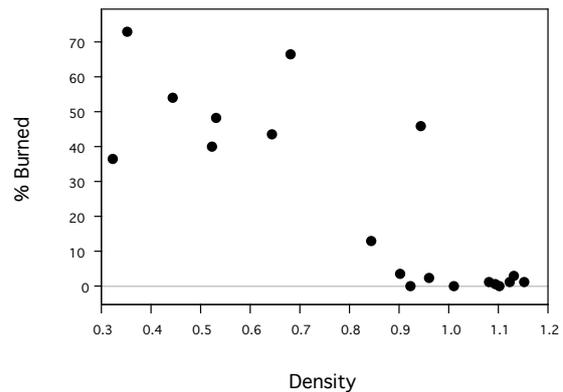


**Fig. 2** - Examples of burned and unburned radio-ulnae from Saint-Césaire. Burned specimens, indicated by arrows, are all completely carbonized epiphyseal fragments.

(Fig. 3). Given the close link that seems to exist between bone density and fat content, it seems reasonable to conclude that the selection of bones for fuel during the Early Aurignacian occupation at Saint-Césaire was essentially determined by fat content. In order to determine whether this conclusion holds for all the levels at Saint-Césaire, it is necessary to consider not only the relationship between bone density and the frequency of burning, but also an additional complicating factor: the relationship between species body size and the identifiability of burned spongy bone.

#### An allometric effect: the impact of body size on the identification of burned bones

In the Early Aurignacian layer at Saint-Césaire, 4.6% (141/3079) of postcranial remains identified to the species level are burned, all taxa included. In contrast, no burned postcranial element (0/483) was determined to the species level in the Châtelperronian level, where bison and horse are strongly represented. This highly significant difference (arcsine transformation, Sokal & Rohlf, 1969: 607-610;  $t_s = 8.83$ ,  $p < 0.0001$ ) is all the more surprising



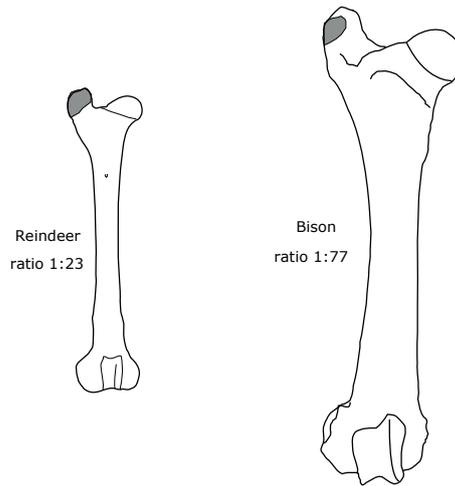
**Fig. 3** - Correlation between the percentage of burned reindeer bones in the Early Aurignacian level of Saint-Césaire and bone density (Lam *et al.*, 1999). Data from Table 2. Phalanges are excluded from the analysis, and only elements with frequencies greater than or equal to 10 are included in the graph.

considering that the percentage of burned bones (Fig. 4a) and the anatomical profiles of the two levels are generally comparable, in spite of minor variations (Morin, 2004). Given this similarity, how can the low rate of identification of burned postcranial remains in the Châtelperronian level be explained?

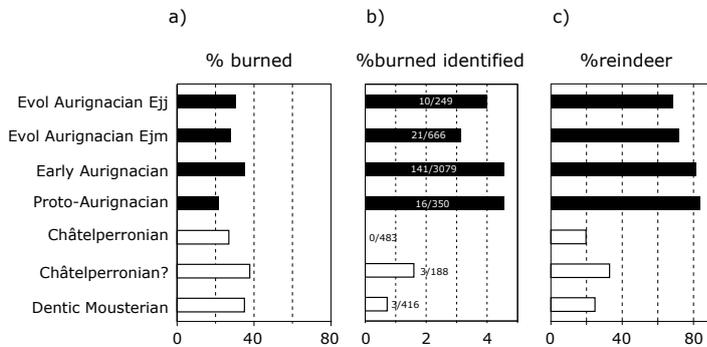
The last two graphs in Figure 4 suggest a link between body size of the taxa dominating an assemblage and



the percentage of burned postcranial remains identified to species. At Saint-Césaire, only small percentages of burned bones were identified to species in the lower levels (the Mousterian and Châtelperronian) where bison and horse are abundant. In contrast, the identification rates of burned remains are much higher in the upper (Aurignacian) levels, which are dominated by the smaller-bodied reindeer. Given the similarities in the anatomical profiles between these two sets of layers, it seems unlikely that this co-variation is purely accidental. The low identification rate of burned bones in the lower layers may signal an allometric relationship in which remains of large-bodied species are less frequently identified when burned than the remains of small-bodied species. The explanation proposed here for this phenomenon is that it is caused



**Fig. 5** - Fraction represented by an archaeological burned bone fragment of reindeer and bison relative to a complete bone. In this example, the fragment of bison is three times smaller, relative to the complete bone, than the reindeer fragment.



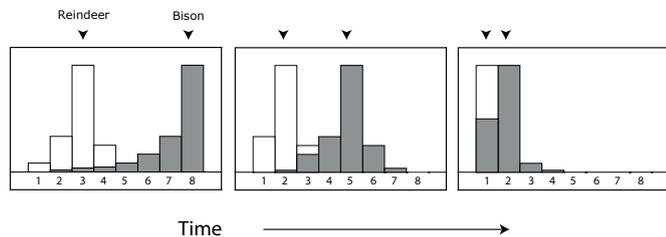
**Fig. 4** - Percentage of (a) burned bones and (b) identified burned bones compared to (c) the relative abundance of reindeer in the different levels of Saint-Césaire. White bars indicate levels dominated by bison, horse, and reindeer, while black bars indicate levels dominated by reindeer alone. The raw data for graphs (a) and (c) are from Morin (2004: 141-142, 191).

by a difference between small- and large-bodied taxa in the ratio of the surface area of burned fragments relative to the total surface area of the whole bone portion or element. This hypothesis requires some additional comments.

At Saint-Césaire, the average size of unidentified fragments of burned spongy bone varies less between levels than might be expected based on taxonomic composition. If this general impression is accurate, unidentified burned spongy bones of bison and horse would be *proportionally* more fragmented than those of reindeer. Consequently, as illustrated in Figure 5, spongy bone fragments

of large taxa possibly sample a smaller fraction of the complete skeletal element than fragmentary remains of reindeer. This relative difference in size reduces the probability of identification of larger taxa. The next step consists of determining the reasons for this differential fragmentation. It is possible that the distributions of bone fragment size for small- and large-bodied species, which differed subsequent to marrow cracking, gradually converged due to the cumulative effects of combustion and post-depositional breakage (Fig. 6). The increasing overlap between the curves of fragment size distribution may be

explained by the greater fragility of spongy bone fragments



**Fig. 6** - Theoretical temporal progression of the size of burned spongy bone fragments of reindeer and bison. In this example, the average size of burned bison fragments decreases more rapidly than that of reindeer due to the cumulative effects of combustion and post-depositional breakage. The arrows above the graphs indicate the average fragment size for each distribution. Numbers under the columns indicate hypothetical size classes of bone fragments.



belonging to large ungulates. Experimental work will be necessary to test these hypotheses.

## Discussion and conclusion

For at least two reasons, differential preservation cannot be identified solely on the basis of a statistical correlation between anatomical profiles and bone density. The first reason is that such a correlation, *by comparing an archaeological anatomical profile to that of a living animal*, presupposes that whole carcasses were initially deposited at the site. This assumption is particularly dubious when assemblages consist of large ungulates, given the logistical constraints linked to the transport of these animals (O'Connell *et al.*, 1990; Lyman, 1994; Lam & Pearson, 2005). The second, more clearly defined, problem is one of equifinality: an underrepresentation of spongy bone may have several causes, including carnivore attrition, bone grease production, or as we have seen here, the use of bone as fuel.

At Saint-Césaire, anatomical profiles appear to reflect the effects of combustion, which makes the examination of differential preservation difficult. The same pattern also seems to characterize assemblages from Grotte du Renne at Arcy-sur-Cure (David & Poulain, 2002), Cuzoul du Vers, Combe-Saunière (Castel, 1999), and Saint-Germain-la-Rivière (Costamagno, 1999). Potential solutions to this problem involve considering only unburned elements, or considering only *unburned bones of similar density*, an approach that significantly reduces the problem of differential preservation (see also Marean & Cleghorn, 2002). This second option was the one adopted in the analysis of the Saint-Césaire material (Morin, 2004: 302–304).

An additional problem raised in this article concerns the impact of species body size on the identification of fragments. At Saint-Césaire, burned spongy bone fragments of bison and horse are less frequently identified than those of reindeer. This differential identification can be attributed to two factors. First, spongy bone fragments of large ungulates are possibly more affected by combustion and post-depositional breakage than bone fragments of smaller ungulates. Secondly, the fragment

area/element area ratio appears to be smaller for bison and horse than for reindeer, which renders identification of the larger species more difficult. Additional studies will show whether these conclusions hold for faunal assemblages from other sites.

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