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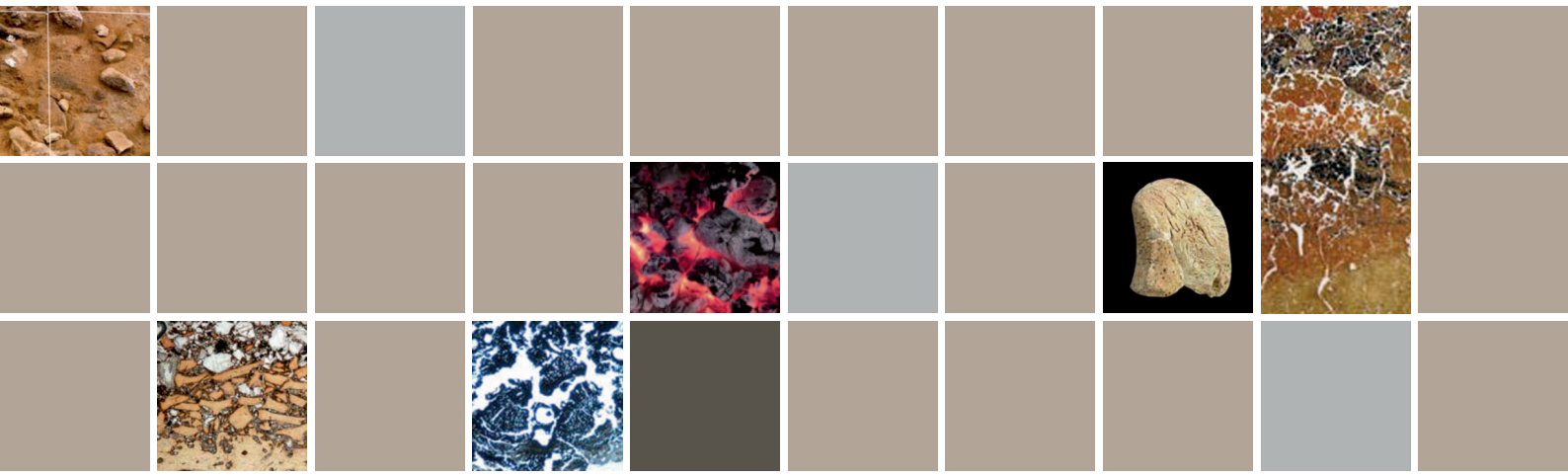
THE TAPHONOMY OF BURNED ORGANIC RESIDUES AND COMBUSTION FEATURES IN ARCHAEOLOGICAL CONTEXTS



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THE ACTION OF *WEATHERING* ON BURNED BONE: AN EXPERIMENTAL APPROACH

Magali GERBE

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Abstract

The alteration of bones following exposure to weathering is today well known, but it is possible that burned bones do not suffer the same type of changes since their physicochemical properties are modified by combustion. A series of experiments has been carried out with the aim of better understanding these reactions. These experiments form part of a more widespread attempt to better understand the impact of taphonomic agents on burned bones in order to estimate the distortions between bone material originating from experimental combustion and the fossil material.

Five experimental series resulting from the combustion of fresh cow humeri were exposed for eighteen months to weathering in a Mediterranean context. Several criteria were observed in order to highlight the impact of this exposure on the burned bones: degree of fragmentation, loss of bone mass, alteration of bone surface, influence of the degree of combustion (carbonised vs charred) and of the bone tissue (spongy vs compact) on the preservation of the material.

The results of these experiments mainly show a high fragmentation of the material (the small burned bones being in the majority), associated with a reduction in bone mass. In addition, spongy and charred bones have an increased sensitivity to the action of weathering, leading to their destruction. A preferential preservation of charred compact bone is thus expected.

Keywords : burned bones, bone fuel, experimentation, taphonomy, weathering

Introduction

Various studies have been conducted in order to understand the presence of burned bones discovered on archaeological sites. The proportion of these bones, whether or not associated with structures and other combustion materials (hearth, charcoals, ash, etc.), is sometimes very large. The main objective of these investigations was to determine the origin and nature of bone combustion: natural fire and accidental combustion *versus* anthropogenic origin (Spennemann & Colley, 1989; David, 1990; Stiner *et al.*, 1995; Bennett, 1999; Costamagno *et al.*, in press); and in the latter case, ignition origin: use of the bone as fuel (Costamagno *et al.*, in press), camp maintenance (Walters, 1988; Cain, 2005), culinary remains (Vigne *et al.*, 1981; Vigne, 1983; Walters, 1988; Laroulandie, 2001). These studies tend to focus on two complementary aspects:

1) the combustible properties of bone according to their tissue (spongy *vs* compact) and their state of freshness and fragmentation (Gilchrist & Mytum, 1986; Guillon, 1986; Buikstra & Sweggle, 1989; Spennemann & Colley, 1989; Fernandez Jalvo & Perales Piquer, 1990; Costamagno *et al*., 1999, 2005; Théry-Parisot, 2002; Théry-Parisot *et al*., 2004, 2005; Théry-Parisot & Costamagno, 2005; Mentzer, in press);

2) the modifications in colour and structure of the bone tissue according to the combustion temperature (Herrmann, 1977; Perinet, 1982; Shipman *et al*., 1984; Brain & Sillen, 1988; Susini, 1988; Spennemann & Colley, 1989; Brain, 1993; Nicholson, 1993; Sillen & Hoering, 1993; Stiner *et al*., 1995; Taylor *et al*., 1995; Trellisó Carreño, 2001; Joly & March, 2003; Pastó, 2003; Hanson & Cain, 2007).

The work conducted in connection with intentional combustion has highlighted, on one hand, more efficient combustion of the extremities of fresh long bones; on the other, high fragmentation of the bones, producing a majority of remains of small size (less than 2 cm), essentially charred (Costamagno *et al*., 2005; Théry-Parisot *et al*., 2004, 2005; Théry-Parisot & Costamagno, 2005).

In spite of these advances, several questions remain. In the majority of sites where burned bones are present in large numbers, the remains are mainly carbonised (black or brown) and not charred (white or grey). The hypothesis of greater fragility of charred bones as a result of the taphonomic filter is generally suggested. But combustion strongly modifies the physico-chemical properties of bones, so the behaviour of unburned bone when exposed to pre- and post-burial agents is thus not directly transferable to burned bone.

The few studies available on the subject highlight the different properties of burned bones when exposed to the various taphonomic agents. For some authors, burned bones are more vulnerable than unburned bones when subject to mechanical stresses (David, 1990; Stiner *et al.,* 1995), while for others, only burned bones would be preserved in poor preservation conditions, such as acidic soils (Gilchrist & Mytum, 1986). In recent years, studies on the taphonomy of burned bones have been carried out in order to better understand the response of burned bones to different taphonomic agents. The first approach to consider is the possible staining of bones after burial, when they are in contact with certain minerals in the soil (Franchet, 1933). The best known of these is manganese (Brain & Sillen, 1988; Shahack-Gross *et al*., 1997) which colours bones black, thus imitating a carbonised appearance. The impact of trampling (mechanical action) on burned bones has also been studied. High fragmentation of this category of remains and a greater sensitivity of charred bones relative to carbonised bones can be observed (Stiner *et al*., 1995). A study of trampling by modern bison of burned bones confirms these remarks, to which must be added the higher destruction rate of spongy tissue compared to compact tissue (Thiébaut *et al*., in press).

These studies concern post-burial processes, but burned bones are also subject to pre-burial agents. The work presented here fits into this context, with the aim of better understanding the impact of weathering on the differential preservation of burned bones: is loss of mass important? Are the bones more fragmented? What is the influence of the initial degree of bone fragmentation, the bone tissue (spongy *vs* compact) and

the combustion intensity in the preservation, and thus the representation, of burned bones?

Materials and methods

The experimental material originates from combustions realised with adult cow humeri, following various protocols (*cf.* Théry-Parisot *et al.*, 2004, 2005 for a detailed description). The bone residues resulting from five experimental series were exposed to weathering:

- complete fresh proximal extremities
- fractured fresh proximal extremities
- complete fresh distal extremities
- fractured fresh distal extremities
- fresh whole humeri

Each series is comprised of a number of humeri (or portions of humeri), and thus of a bone mass, known before its deposit in the hearth (table 1). After each combustion, all of the ash was sieved in order to recover all bone remains.

Série	Nombre d'os	Poids
Extrémité proximale complète	10	11010
Extrémité proximale fracturée	10	6776
Extrémité distale complète	10	8400
Extrémité distale fracturée	10	5373
Humérus entier	20	11183

Tab. 1 : Description of the series, before combustion.

Before exposure to weathering, all of the burned bone remains were sorted, weighed and counted by size-class of one centimetre, tissue type, and combustion intensity. The 0-1 cm size-class was only weighed as a whole. Combustion intensity (Nicholson, 1993) relates to bone colour, five stages having been noted, from the most intensely burned to unburned: white, grey, black, brown, unburned. (Stiner *et al.*, 1995, modified by Castel, 1999 and Costamagno, 1999). The colour present over the majority of the bone fragment is taken into account, with no distinction being made between external and internal surfaces. For the bone tissues, three types were selected: compact, spongy and compact-spongy tissue.

Each series was then deposited separately in perforated wooden boxes, the bases of which were covered with a fine-mesh grill in order to prevent any loss of material, and placed on the roof of the CEPAM-UMR 6130 building (Valbonne, Alpes-Maritimes). The bones were exposed to the elements for eighteen months: from June 10, 2002 to November 6, 2003. The burned bones were subject to a Mediterranean-type climate (contrasting temperatures and irregular precipitation), constituting a transition between the temperate and tropical climates. It should be noted that summer 2003 was an abnormally dry period (a four month heat wave) during which precipitation was zero (fig. 1).

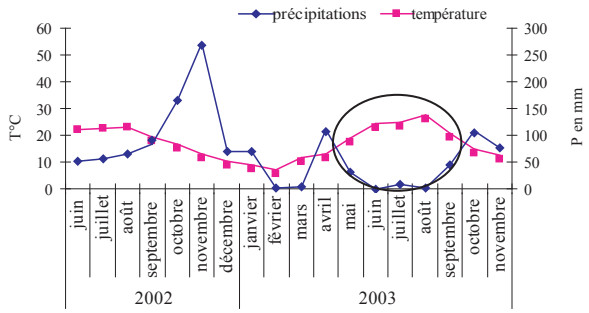

Fig. 1 : Ombrothermal diagram, Sophia-Antipolis site (data Météo France) black oval = dry period.

After exposure, the bones were sorted, weighed and counted according to the initial criteria. Observations of the surfaces (fissuring) were also made to allow comparison with the data resulting from work on the weathering of unburned bones (Behrensmeyer, 1978).

In order to evaluate the degree of fragmentation of the experimental material, an index was calculated which consisted of dividing the post-exposure number of remains (NR) by the pre-exposure NR. When the value is 1, fragmentation is zero; the higher the value, the greater the fragmentation.

Finally, a statistical analysis was employed to determin whether the differences observed between the series were significant or not. The presence of values that are too low (less than five) in the contingency tables makes it impossible perform a Chi-square analysis (Everitt, 1996). Similarly, the values that are too high for certain categories do not allow the application of an unmodified Fisher's Exact Test (F) and for this reason, a Monte Carlo was first performed. This latter produces a random sampling which then permits the application of Fisher's Exact Test, allowing data homogeneity to be tested (Everitt, 1996). The adjusted

values for each cell of the contingency table are observed; those for which the values are higher than two are significantly different (for $P < 0.05$) according to Fisher's Exact Test.

Results

The results are presented according to three analysis criteria: the state of the surfaces; the post-depositional fragmentation of the material and the bone mass. For the two latter issues, the influence of the bone tissue, combustion intensity and fragmentation intensity are taken into account in order to explain the evolution of the experimental series before and after exposure to weathering.

Surface fissuring

The action of atmospheric agents (in relation with the climate *s.l.*) on bones, more commonly known as *weathering,* has been defined by A.K. Behrensmeyer as: "*the process by which the original microscopic organic and inorganic components of a bone are separated from each other and destroyed by physical and chemical agents operating on the bone* in situ*, either on the surface or within the soil zone"* (Behrensmeyer, 1978, 153). In other words, this process is the structural response of skeletal elements to a set of complex actions governed by the climate, involving both exposure to wind, sun, rain, snow, etc., and interactions with the local sedimentary context (Lyman & Fox, 1989).

This response is mainly illustrated by fissuring, desquamation and other cracking of the bone surface, which progressively results in a near-total alteration and destruction of the bones (six stages of alteration have been given by Behrensemeyer, *op.cit.*, in a tropical context). However, this observation criterion proves to be inoperative in the case of burned bones since the bone surfaces fissure during combustion (Shipman *et al.*, 1984; Fernandez Jalvo & Perales Piquer, 1990; Stiner *et al.*, 1995; Taylor *et al.*, 1995; Hanson & Cain, 2007). It thus becomes impossible to distinguish macroscopically between fissures due to combustion from those resulting from exposure to weathering. This criterion is thus abandoned in assessing the effect of weathering on burned bones.

Post-depositional fragmentation

The fragmentation of the burned bone residues is highlighted by the fragmentation index (table 2) since the number of remains is doubled for the extremities, both complete and fractured. However, the whole humerus shows a small increase (index = 1.04) that can be related to the presence of the diaphysis, i.e., of *compacta*, an anatomical part absent in the other experimental series. Figure 2 illustrates this difference since the series relating to the whole humerus is the only one having a large number of compact bone remains both before exposure (n = 224) and after exposure (n = 556).

Série expérimentale	Indice de fragmentation
Extrémité proximale complète	2,33
Extrémité proximale fracturée	2,52
Extrémité distale complète	2,01
Extrémité distale fracturée	2, 07
Humérus entier	1, 04

Tab. 2 : Fragmentation index by experimental series.

The fragmentation index is shown to be correlated wih a reduction in size of the burned bones, the majority of these being fragmented into remains lower than 4 cm in size (fig. 3), the number of remains increasing by up to 50% for the small size-classes. However, not all of the series react in the same way. There is a clear non-homogeneity between the series (table 3), particularly in the distribution of the remains of small size.

Therefore, the proximal extremities show an increased number of remains in all size-classes, while for the distal extremities a reduction in remains between 6 and 10 cm is observed (fig. 3). This difference is due to the fact that the extremities that remained whole after combustion and fragments larger than 12 cm are not present before exposure, for the distal extremities. Regarding the whole humerus, the general trend in the number of remains

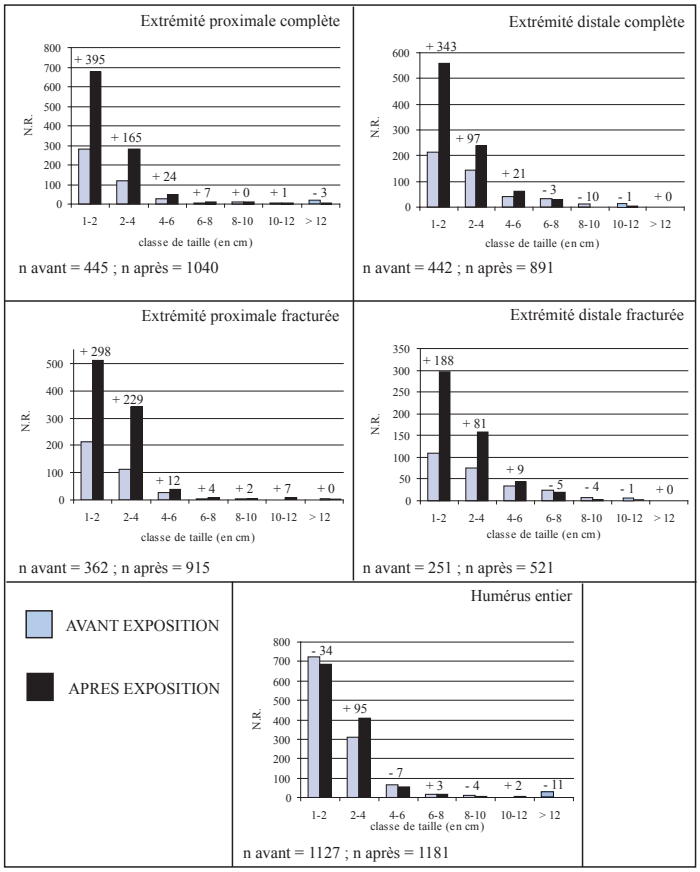

Fig. 2 : Distribution of burned bones according to bone tissue. N.R. = Number of Remains. % = percentage difference before/after exposure.

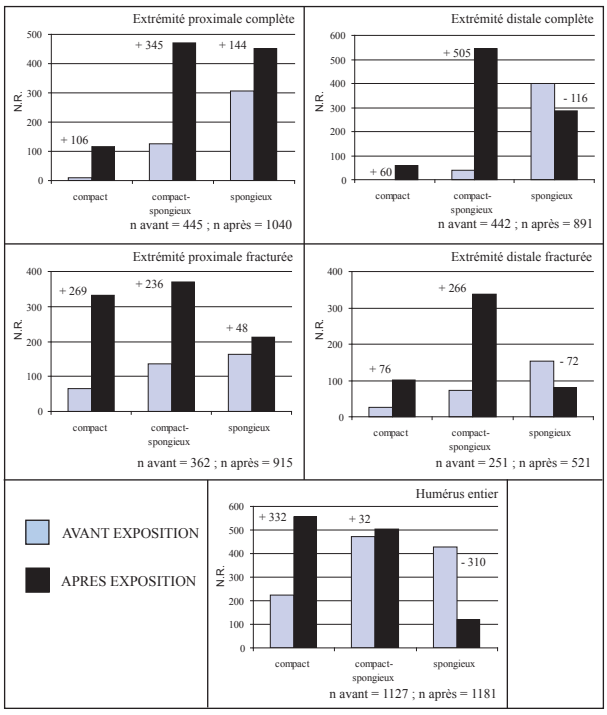

Fig. 3 : Fragmentation of the bone residues before and after exposure. N.R.: Number of Remains. % = percentage difference before/after exposure.

by size-class differs from the other series: contrary to these latter, few small fragments are generated after exposure to weathering. Once again, the greater presence of *compacta* and the quantity of charred bones explains this dissimilarity. Burned spongy bone crumbles more easily than compact bone (Gerbe, 2004) and charred bones appear to be more sensitive to fragmentation.

Regarding the first point, it appears that spongy bone tends to fragment and disappear upon exposure to weathering (fig. 2). Two tendencies can be observed: a reduction in the number of remains for the whole humeri and distal extremities, and an increase in the number of remains for the proximal extremities. The divergence between the proximal and distal extremities results from a higher proportion of *spongiosa* in the proximal extremity of the humerus, the distal extremity comprising slightly more *compacta*, which explains why the number of remains of burned spongy bone would be

Classe taille (en cm)		ext. px. co	ext. px. fr	ext. ds. co	ext. ds. fr	hum. entier
1-2	décompte	678	512	557	297	688
	valeur ajustée	**3.8**	**2.8**	1.7	1.5	1.5
2-3	décompte	204	270	164	109	318
	valeur ajustée	**3.3**	**4.9**	**3.9**	1.4	**3.3**
3-4	décompte	78	71	75	48	88
	valeur ajustée	0.6	0.2	0.6	1.2	0.7
4-5	décompte	37	23	40	27	38
	valeur ajustée	0.1	**2.0**	1.5	**2.0**	0.9
5-6	décompte	12	17	22	17	19
	valeur ajustée	**2.0**	0.1	1.4	**2.4**	0.9
6-7	décompte	6	6	19	14	11
	valeur ajustée	**2.2**	1.8	**2.7**	**3.2**	1.1
7-8	décompte	6	3	9	5	7
	valeur ajustée	0.4	1.4	1.4	0.9	0.3
8-9	décompte	5	3	1	2	5
	valeur ajustée	0.8	0.1	1.3	0.1	0.5
9-10	décompte	5	2	1	1	2
	valeur ajustée	1.8	0.2	0.9	0.2	0.6
10-11	décompte	5	4	1	1	2
	valeur ajustée	1.3	1.0	1.1	0.4	0.9
11-12	décompte	1	3	2	0	1
	valeur ajustée	0.5	1.5	0.6	1.0	0.7
12-13	décompte	2	1	0	0	2
	valeur ajustée	0.9	0.0	1.1	0.8	0.7
13-14	décompte	1	0	0	0	0
	valeur ajustée	1.8	0.5	0.5	0.4	0.6

Tab. 3 : Contingency table of the distribution of bone fragments by size-class and by experimental series, with note of adjusted values.
ext.: extremity; px.: proximal; ds.: distal; co.: complete; fr.: fractured; hum.: humerus

increased for the proximal extremities. Regarding whole bone, the presence of *compacta* in the diaphysis weights the proportion of spongy bone, which is consequently under-represented. The pronounced non-homogeneity of the data (table 4) can be explained by these two trends, nearly all of the values being significantly different. The distribution of bone tissue according to size-class (fig. 4) confirms these dissimilarities, the majority of fragments of *spongiosa* being contained in the category 0-2 cm, while the "compact-spongy" and "compact" fragments have a less grouped distribution, with more remains in the size-classes above 4 cm, particularly for compact-spongy bone. Fragmentation thus has a significant impact on the spongy fragments in reducing their size, a reduction that can continue until the fragments crumble completely and thus eventually disappear.

Classe taille (en cm)		ext. px. co	ext. px. fr	ext. ds. co	ext. ds. fr	hum. entier
compact	décompte	116	333	60	102	556
	valeur ajustée	**12.2**	**8.3**	**14.4**	**3.4**	**19.6**
compact-sponieux	décompte	472	371	546	338	505
	valeur ajustée	**2.7**	**5.8**	**8.1**	**7.7**	**5.0**
spongieux	décompte	452	211	285	81	120
	valeur ajustée	**15.4**	1.7	**5.2**	**5.4**	**13.9**

Tab. 4 : Contingency table of the distribution of bone fragments by histological tissue and by experimental series, with note of adjusted values.
ext.: extremity; px.: proximal; ds.: distal; co.: complete; fr.: fractured; hum.: humerus

In addition, fragmentation also affects the most intensely burned bones. Due to their low numbers, the unburned and slightly burned fragments (brown) generally have very little influence on the homogeneity of the series, unlike the more intensely burned fragments (black to white) for which various values are significantly different (table 5). These dissimilarities arise from the differential distribution of the charred remains (white and grey) relative to the carbonised remains (black and brown). These latter fall mainly in the size-classes from 1 to 4 cm (or even 1 to 2 cm), while the charred bones have a wider distribution (fig. 5), including the presence of large fragments (greater than 10 cm). It should therefore be considered that this greater distribution is the origin of the greater quantity of charred remains, since burned bones tend to fragment into smaller remains (*cf. supra*). Moreover, only the charred bones show an increase in numbers for all of the experimental series (fig. 6). However, the whole humeri differ once again from the other series with a smaller increase in this category of bones, particularly for the white fragments. This can be explained by the disappearance of the white spongy residues, which, for the whole humerus, is the highest of all of the experimental series (fig. 7). Combustion intensity thus proves to be a factor in the fragmentation of burned bones, with charred bones being more subject to this phenomenon, all the more so as they are composed of *spongiosa*.

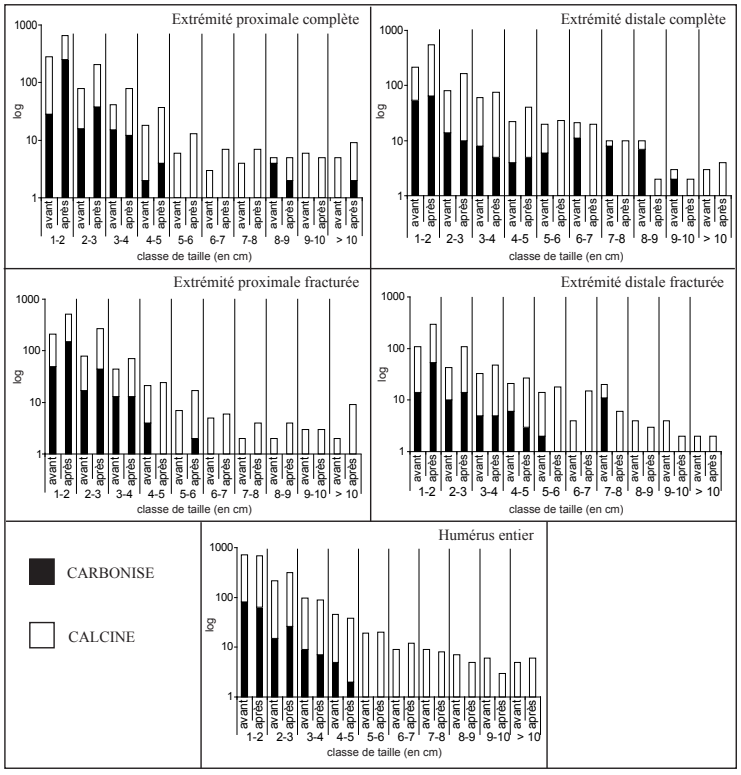

Fig. 4 : Distribution of burned bones according to bone tissue and size-class. N.R.: Number of Remains.

Finally, the presence of unburned or brown coloured remains after exposure, even if these latter were non-existent before exposure, is explained by the fragmentation of partially burned bones (fig. 6 and 7).

Classe taille (en cm)		ext. px. co	ext. px. fr	ext. ds. co	ext. ds. fr	hum. entier
non brûlé	décompte	18	0	4	0	1
	valeur ajustée	**6.3**	**2.4**	0.3	1.7	**2.4**
marron	décompte	98	127	66	44	62
	valeur ajustée	0.9	**6.2**	1.6	0.2	**4.9**
noir	décompte	214	82	19	102	37
	valeur ajustée	**13.0**	1.2	**8.7**	**7.8**	**9.1**
gris	décompte	295	334	318	98	350
	valeur ajustée	1.8	**4.3**	**3.6**	**6.2**	0.9
blanc	décompte	415	372	484	277	731
	valeur ajustée	**7.5**	**6.4**	**2.8**	1.5	**9.4**

Tab. 5 : Contingency table of the distribution of bone fragments by combustion intensity and by experimental series, with note of adjusted values.
ext.: extremity; px.: proximal; ds.: distal; co.: complete; fr.: fractured; hum.: humerus

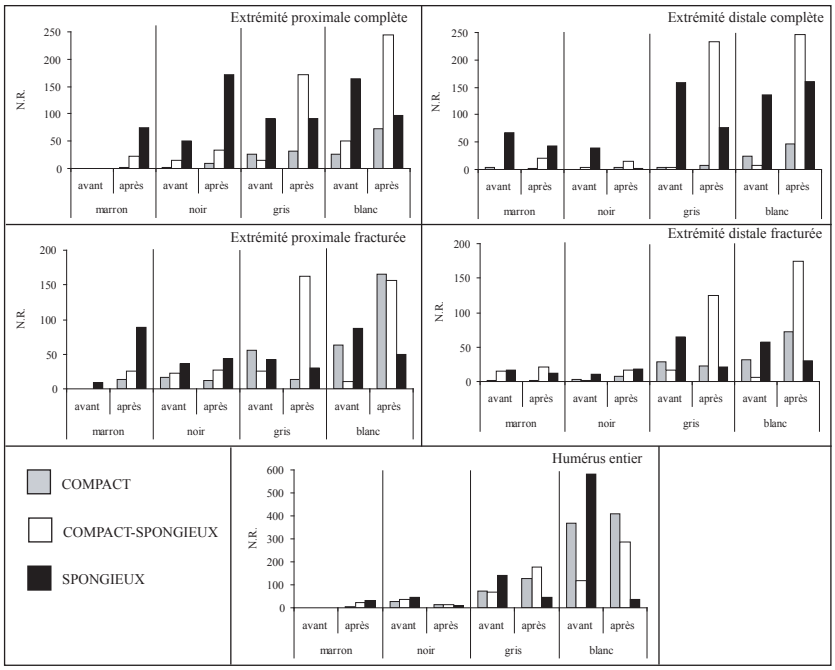

Fig. 5 : Distribution of burned bones according to combustion intensity and size-class. N.R.: Number of Remains. charred = white and grey; carbonised = black and brown the unburned bones are excluded from the count

Residual mass after exposure

The observed fragmentation and disappearance of burned residues after exposure should also be expressed in the residual bone mass. In order to address this question, the distribution of mass according to size-class, combustion intensity and bone tissue was examined. For the two latter criteria, the whole extremities before exposure and the fragments larger than 12 cm[1] after exposure are removed from the count in order to harmonise the data to be compared.

A reduction in bone mass is noted after exposure to weathering for all of the experimental series (table 6). This deficit is quite small for the whole extremities used (2 to 4%) and higher (8 to 10%) for the extremities that were fractured in advance and for the whole humerus (10%). This weight loss can mainly be explained by the distribution of the burned remains. The increase in weight of the small size-classes is due to the fragmentation of the remains of larger size (*cf. supra*), particularly the extremities (fig. 8). The series concerning the proximal extremity and whole humerus show a net reduction in mass for the 12-14 cm size-class and an increase in mass for the smaller size-classes. For the distal extremities, we observe a reduction in mass up to 6 cm, then an increase for the smaller categories. The bone mass loss thus results from the intense fragmentation of the material. If an exposure time to weathering of more than a year and a half is considered, it is imaginable that the bone mass would continue to decrease, and that the mass of burned bone then measured would no longer be representative of the initial bone mass of the deposited bones.

The hypothesis of increased fragility of the spongy bones is confirmed, these latter being the only bone

Série expérimentale	Avant exposition	Après exposition	Différence en gramme
Extrémité proximale complète	2275 g	2188 g	- 87 g
Extrémité proximale fracturée	2117 g	1840 g	- 277 g
Extrémité distale complète	2093 g	1929 g	- 164 g
Extrémité distale fracturée	1889 g	1560 g	- 329 g
Humérus entier	3921 g	3251 g	- 670 g

Tab. 6 : Comparison of bone mass before and after exposure by experimental series.

[1] - fragments larger than 12 cm after exposure result from the fragmentation of the pre-exposure extremities.

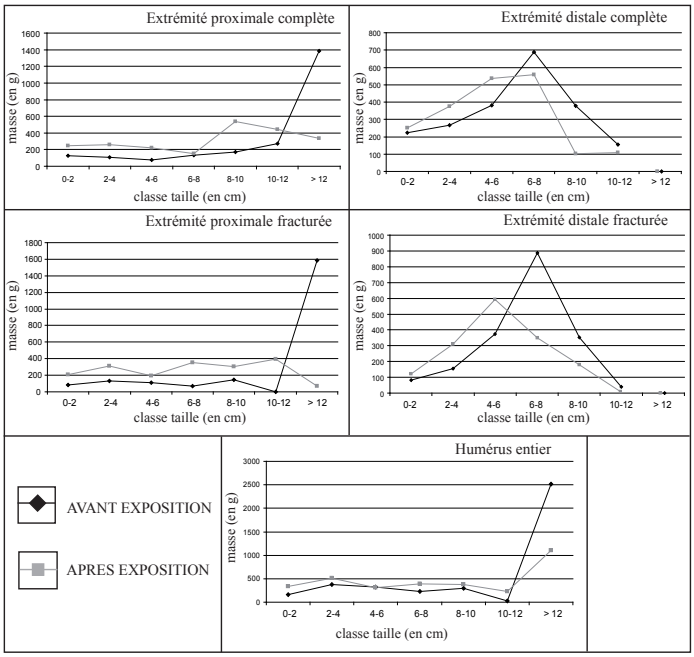

Fig. 6 : Distribution of bone residues according to their degree of combustion. N.R.: Number of Remains
% = percentage difference before/after exposure

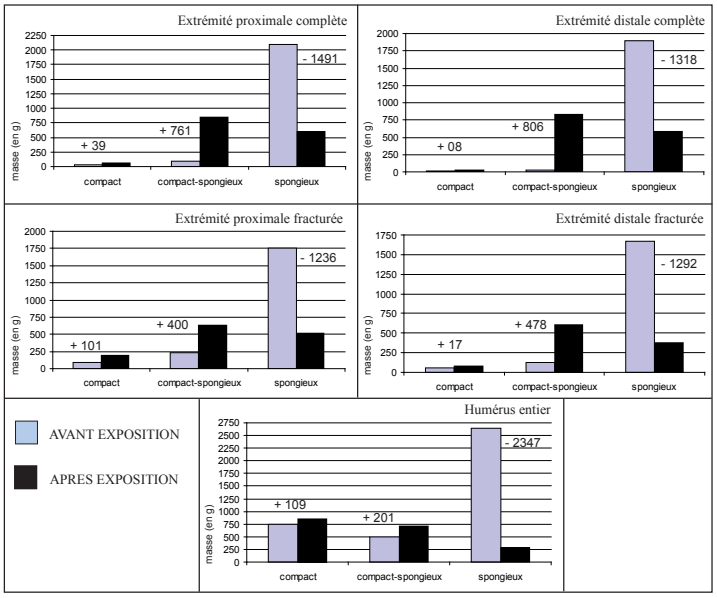

Fig. 7 : Distribution of burned bones according to their tissue and combustion intensity. N.R.: Number of Remains.

tissue to experience a mass reduction after exposure. This weight loss is less pronounced for the proximal extremities compared to the distal extremities, due to the higher proportion of *spongiosa* in the former. The whole humerus undergoes the smallest decrease, but the presence of the diaphysis (and thus of compact bone) explains this difference.

In addition, the fragility of the most intensely burned bones (white) is confirmed, since a weight loss for each of the series is noted for this bone category.

There is therefore a correlation between the loss of bone mass and the fragmentation of burned bones.

Conclusions

Differences have been observed between each of the experimental series. The discrepancies that exist between proximal and distal extremities can be explained by the difference in density of *spongiosa*, which is greater in the proximal extremity of the humerus (Lyman, 1994). Moreover, the experimental series concerning the whole humerus always differs from the others, this peculiarity seeming to result from the presence of the diaphysis (= compact bone). Better characterisation of the differences in reactivity between compact and spongy tissue is therefore necessary and will be feasible in light of other experiments, currently in progress, concerning the exposure of burned bones to weathering (Gavarnie, Hautes-Pyrénées, dir. S. Costamagno; Marvejols, Lozère, dir. M. Gerbe).

Despite these differences, general trends emerge for the whole set of experimental series and allow us to emphasize the influence of weathering on the differential preservation of burned bones. The main impact of this latter consists of fragmentation of the material associated with a bone mass reduction. The burned residues fragment into smaller pieces, fragments of less than 2 cm being quantitatively dominant.

Moreover, the burned spongy bones are made fragile by exposure to weathering, which has the effect of fragmenting them intensely, or even destroying them. The charred bones, particularly those that are white, react in the same manner. Additionally, when all analysis criteria are cross-analysed, we can see that the majority of small-sized burned bones are charred and spongy.

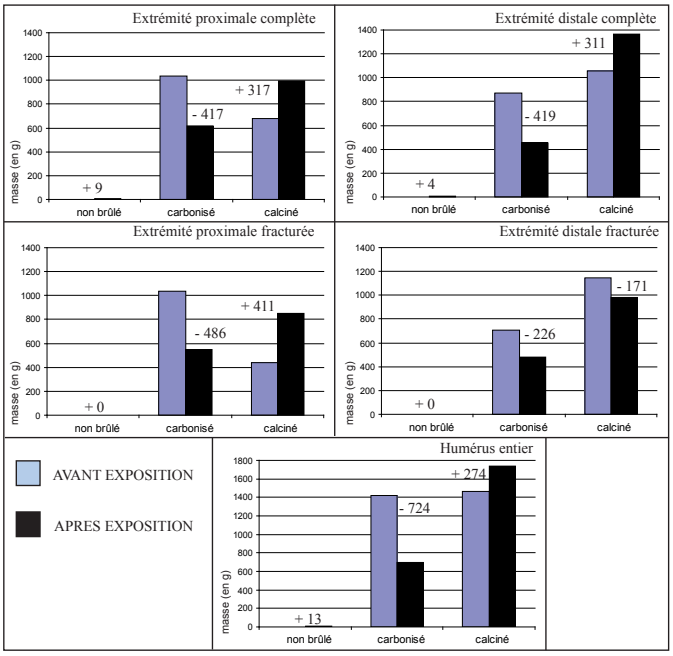

Fig. 8 : Distribution of the bone mass according to size-class. ext.: extremity

In the experiment presented here, the bones were exposed for a year and a half. If they had been exposed for a longer period, one could imagine that the alterations and destructions observed would be accentuated and that, ultimately, the charred bone would disappear like the spongy bone. On the basis of these observations, the premise of preferential preservation of compact and charred burned bone may be advanced for archaeological sites at which the action of weathering is attested.

In the light of experiments already performed, the large quantity of burned bone, mostly less than 2 cm in size, observed in archaeological assemblages (Villa *et al*., 2002; Costamagno *et al*., in press) may result from combustion itself (Théry-Parisot *et al.*, 2004, 2005; Mentzer, in press) and/or from the impact of weathering and/or of trampling (Stiner *et al*., 1995; Thiébaut *et al*., in press).

Finally, in some archaeological assemblages for which the use of bone as fuel is advanced, the hypothesis according to which the rarity of charred remains might be linked to a taphonomic bias (Théry-Parisot *et al*., 2004, 2005; Costamagno *et al*., 2005) is supported by the current study. In addition, given that burned spongy fragments disappear more rapidly than diaphysis fragments, intense weathering may mask the main criterion used to determine the use of bones as fuel, which is the over-representation of burned spongy portions relative to compact bone fragments (Costamagno *et al*., in press). It is thus essential to take into account the taphonomic actions suffered by archaeological remains, as well as their intensity, when formulating hypotheses concerning the origin of burned bones.

In order to explain the diversity observed within various archaeological assemblages, further experiments involving other taphonomic agents are thus necessary.

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