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Deciphering archaeological palimpsests with bone micro-fragments from the Lower Magdalenian of El Mirón cave (Cantabria, Spain)

Running heads:

Historical Biology

J. M. Geiling et al.

Geiling Jeanne Marie [a,] [*]

Marín-Arroyo Ana B. [a]

Straus Lawrence G. [b]

González Morales Manuel R. [a]

[a]*Laboratorio de Bioarqueología, Edificio Interfacultativo, Instituto Internacional de Investigaciones Prehistóricas de Cantabria, Universidad de Cantabria, Santander, Spain* **AQ1**

[b]*Department of Anthropology, University of New Mexico, Albuquerque, NM, USA*

[*]Corresponding author. Email: jeanmarie.geiling@unican.es

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Abstract

Modern excavation techniques aim accurately to recover extant archaeological data. Usually bone micro-fragments are gathered as a result; however, during archaeological analysis these remains are often set apart as indeterminate bones and generally do not contribute to the interpretation of the deposits. How to decipher archaeological palimpsests using these small bone fragments is the aim of this paper. El Mirón Cave, located in northern Iberia, contains a very rich Cantabrian Lower Magdalenian deposit (17–15 uncal ka BP) with high densities of faunal remains and artefacts. Here, we present zooarchaeological, taphonomic and spatial distribution analyses of macromammal finds, including those small bone fragments, accumulated during a series of intensive and repeated human occupations found in the outer vestibule excavation area. Our results show that a broad spectrum of activities was performed there, including meat, marrow and grease processing and waste abandonment. We propose that bone micro-fragments must be considered when addressing human subsistence reconstructions from animal remains, as they represent the leftovers of the *chaîne opératoire* of animal carcass exploitation. The archaeological implications of their inclusion are extremely valuable, especially when deciphering palimpsests. A multidisciplinary approach to study these small animal remains provides information that otherwise would be missed.

Keywords

Zooarchaeology

taphonomy

spatial distribution analysis

density index

Lower Magdalenian

Cantabrian Spain

Introduction

Modern archaeological excavation techniques, particularly in Paleolithic sites, encompass a variety of detailed steps including: piece-plotting of individual finds, collection of the smallest finds by sub-squares and thin spits during fieldwork, fine-mesh water-screening and, finally, sorting (Straus and González-Morales 2012; Mallol and Hernández 2016). All these procedures aim accurately to recover all extant archaeological data in order to understand site formation processes (Schiffer 1996). During archaeozoological laboratory analysis, however, small bone fragments from macromammals are often omitted or even overlooked. These bone micro-fragments we define as normally less than ~5 cm-long bone specimens that are anatomically or taxonomically unidentifiable. They are usually set apart as ‘indeterminate specimens’ and then only ‘identifiable’ bones are studied (Klein and Cruz-Uribe 1984; Outram 2001). These items represent a class of ultimate end-products of the potentially long *chaîne opératoire* of animal carcass exploitation and then should be considered if the whole process aims to be reconstructed. Especially in Paleolithic contexts bone-cracking for marrow extraction and grease-rendering commonly caused substantial fragmentation (Binford 1978a ; Stiner 2002 ; Church and Lyman 2003 ; Théry-Parisot et al. 2005 ; Marquer et al. 2010 ; Janzen et al. 2014 ; Morin and Soulier 2017). The *chaîne opératoire* concept, normally applied to lithic analysis (Bar-Yosef and Van Peer 2009), is used in this context to record the consequent steps of human actions within the continuum from food acquisition to waste abandonment as readable from faunal remains. Food procurement and butchering processes are frequently-performed tasks in hunter-gatherer lifeways that result in human-made bone accumulations, which in turn indicate the significant contribution of macromammal remains in the formation of archaeological sites. The intensity of visible anthropogenic modifications on each bone specimen depends on the type of economic activity carried out and on conservation of the anthropogenic marks. The combination of taphonomic features of faunal remains, as well as their spatial distributions, are useful indicators to understand past human activities related to subsistence behaviour. Here we focus on bone micro-fragments and on the information they preserve, which should not be disregarded.

We use a conceptual framework that includes the idea of smaller fragments are more prone to stay in their place of deposition and are less susceptible to be moved for intentional purposes (Bailey 2007 ; Malinsky-Buller et al. 2011), particularly to a greater degree than larger ones in human-made contexts. These accumulations are less likely to be displaced by deliberate surface cleaning or disturbance by secondary formation processes (Binford 1978b ; Schiffer 1996). Significant natural post-depositional processes, such as water running through archaeological layers, should be excluded as possible causes for altering or disturbing the levels under study. The concepts described above had already been put to use in the analysis of bone distributions at El Mirón Lower Magdalenian human burial (Geiling and Marín-Arroyo 2015). Bone micro-fragments are markers of activity zones and living floors in relatively stable archaeological levels, as they represent mostly residual primary refuse, such as small artefact manufacturing debris of antler, bone or stone (O'Connell et al. 1991 ; Nakazawa 2007 ; Marín-Arroyo 2009a ; Ullah et al. 2015 ; Geiling et al. 2016).

Archaeological spatial analyses have to deal with the fact that long and/or repeated occupations of cave sites create often very thick palimpsest layers (Straus 1979, 1990). Later, during interpretation, archaeologists tend to 'lump' the residues of multiple occupations together (Bailey 2007 ; Straus 2008 ; Machado and Pérez 2016). This procedure further contributes to the nature of palimpsests. The term 'palimpsest' archaeologically describes the amalgamation of living surfaces with repeated or continues occupations overprinted by younger deposits and activities that usually make recognising single events difficult or impossible (Bailey 2007). Spatial analyses in palimpsest contexts can be guided by some spatially structured activities (such as those 'anchored' by hearths) and refits of artefacts or bones that help deciphering this kind of accumulations (Ferring 1984 ; Marín-Arroyo 2005 ; Straus 2008). More usual, however, are time-averaged palimpsests from which researchers study substantial long-term characteristics of a cultural period. But, depending to the type of research question addressed, these palimpsests need to be untangled or dissected to reconstruct individual human activities.

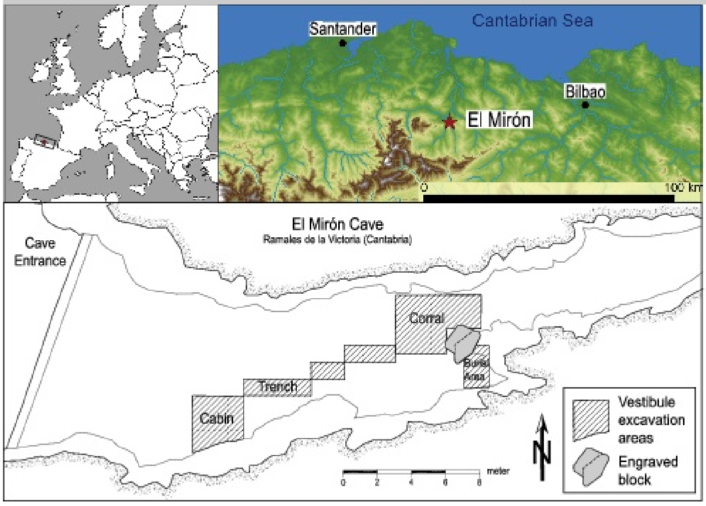
Comparable to other Lower Magdalenian occupations excavated in caves such as Altamira, El Juyo, El Rascaño and El Castillo in Cantabria or Santimamiñe in nearby Vizcaya (Utrilla-Miranda 1981 ; Cabrera-Valdés 1984 ; López Quintana 2011 ; Straus 2013 ; Fontes et al. 2016), it has been proposed that the Lower Magdalenian deposit in El Mirón represents a massive palimpsest of similar, repeated human occupations (Straus et al. 2016), with little evidence for justifying archaeological subdivisions.

In an attempt to deal with the above-described problem of palimpsests, we use the density of macromammal bone micro-fragments sorted into taphonomic categories to test the variability among human occupations through space and time and, to evaluate the Lower Magdalenian subsistence-related human activities (compare Geiling et al. 2016). The methodology proposed, by including bone-micro fragments to decipher archaeological palimpsests, has allowed us to identify locations of specific past human activities.

Materials

El Mirón Cave is a recently excavated archaeological site located at 260 m.a.s.l. on the northern edge of the Cantabrian Cordillera in eastern Cantabria (Figure 1). The large, west-facing, vestibule of the cave revealed a long, well-dated stratigraphic sequence extending from the Middle Paleolithic to the Bronze Age (Straus and González-Morales 2003, 2007, 2010, 2012; Straus, González Morales, Higham, et al. 2015). During excavations from 1996 to 2013 (directed by L.G. Straus and M.R. González Morales), lithics over 1 cm, bones over 5 cm, teeth and osseous artefacts were individually recorded and piece-plotted. Sediments of excavated spit and quarter-metre sub-square units were water-screened and smaller lithic or bone fragments were collected in 'general bags'. This study uses data from Levels 15, 16 and 17, which together form a very rich Lower Magdalenian horizon (15.7–15 uncal ky BP) excavated in an area of 9.5 m^2, in the so-called 'Cabin' area, located in the outer part of the cave vestibule (Figure 1). The studied levels are well preserved and no disturbances among the sediments were observed either during excavation or in sedimentological analysis (Farrand 2012). The Lower Magdalenian deposit in El Mirón is highly organic (charcoal-speckled) and rich in lithic and osseous artefacts, portable art objects, personal adornments, hearths, fire-cracked rocks and intensively processed faunal remains (Fontes et al. 2017; Marín-Arroyo and Geiling 2015; Straus et al. 2016; Fontes et al. 2016; Geiling et al. 2016). The first Magdalenian human burial found in Iberia was discovered at the rear of the cave vestibule (~~Fontes et al. Forthcoming;~~ Straus et al. 2011, 2015 ; Please delete: Marín-Arroyo and Geiling 2015, Straus et al. 2016, Fontes et al. 2016, Geiling et al. 2016 within this sentence and include it to the reference in the sentence before. ~~Marín-Arroyo and Geiling~~ ~~2015~~; ~~Straus et al.~~ ~~2016~~; ~~Fontes et al.~~ ~~2016~~; ~~Geiling et al.~~ ~~2016~~). Among other portable art, the presence of a red deer stag scapula, with the engraving of a red deer hind, and other fragile objects such as antler points and bone needles support the assumption that Level 17 enjoyed excellent preservation conditions (González Morales and Straus 2009). The nature of the archaeological deposits and its preservation state make El Mirón cave suitable for the analytical approach proposed here.

Figure 1. El Mirón cave is located in Northern Iberia in the mountain range. Studied materials origin from the excavation area in the outer AQ8 vestibule (‘Cabin’). (Cave plan by GIM GEOMATICS, MRGM, modified by JMG)



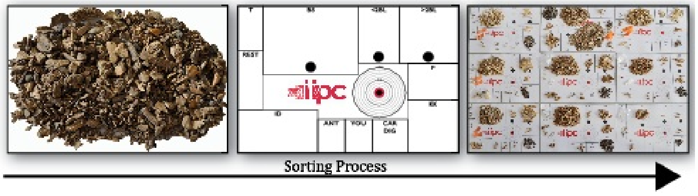
Methods

Macrofaunal study samples and taphonomic categories

For this analysis, we examined the macrofaunal assemblages from Levels 15, 16 and 17 in the outer vestibule area and compared horizontal faunal study units. As shown by the stratigraphic sections and the ~0° angle of elongated objects such as long bones and cobbles, these levels are virtually horizontal. Those study units were made by subdividing the Lower Magdalenian sequence of level 15, 16 and 17. We created 12 sub-samples throughout the levels, which was made possible by meticulous individual find piece-plotting and depth measurements of the top and bottom of every sub-square corner for each excavated spit. The deposit from 15.25 to 15.85 m above datum was split in 12 arbitrary layers each around 5 cm-thick and sometimes each layer composed of more than one excavation ‘spit’. In our analyses, we included all the materials from Levels 15 and 16, corresponding to our samples 1–5. However, because of the overwhelming richness of Level 17, we analysed only its even-numbered samples (6, 8, 10 and 12). All macrofaunal remains were, when possible, anatomically and taxonomically identified using standard archaeozoological methods (comparable to Marín-Arroyo 2009b, 2010) and we use NISP as a quantification index of anatomical elements.

The anatomically and taxonomically unidentifiable bone micro-fragments, were recovered after sieving sediments of each spit units and gathered in ‘general bags’. These micro-fragments were separated into taphonomic categories by using sorting maps specifically made for this type of analysis. These laminated printout displays (templates) have spaces for each previously defined category into which to sort the bones, helping significantly to speed up the sorting process (compare Figure 2). General bags usually contain some small identifiable bones (<5 cm) such as carpals, tarsals, phalanges and sesamoids. Once separated, these items were registered individually in the faunal database, together with worked bone and antler pieces. The taphonomic categories used in this study are designed to address different questions and to provide more details about the accumulation history of the archaeological deposit. Specific attention is given to identify anthropogenic modifications such as carcass processing but also to other biostratinomic and diagenetic alterations. Subsequently, taphonomic categories have been organised according to our research aim. In the case where an item would fall into two or more categories, here in this study priority has been given to anthropogenic modification before a carnivore activity; before diagenetic alterations and before unaltered material categories. In this context we have used bone flakes (defined as intentionally green-fractured bone fragments with a clear striking platform, often a bulb, and sometimes visible bulb scars) as evidence of anthropogenic actions. Burned bones, which include colour variations that range from slightly carbonised- black to half-calcined- white bones (Stiner et al. 1995), are also indicators of human activity, despite where a differentiation between intentional and accidental origin were not possible. Gnawing and digestion marks (Haynes 1983 ; Marín-Arroyo and Margalida 2011 ; Domínguez-Rodrigo et al. 2015) could be indicative of direct carnivore or bird of prey activities. The presence of porous (i.e. fetal, neonatal and young animals) bones reveals very good preservation conditions activities. The presence of porous (i.e. fetal, neonatal and young animals) bones reveals very good preservation conditions at the site. Other sorting categories were spongy and long bone shaft fragments (separated into less and more than 2 cm), antlers and teeth. We sorted, counted and weighted all the items of each category. The results are entered into the working database for indices calculations.

Figure 2. General bag sorting via sorting maps, which facilitate and accelerate the working process of sorting bone refuse within taphonomic categories (T = teeth, BS = spongy bone, BL = long bone; F = bone flakes; KK = burnt bone; CAR/DIG = carnivore activity-digested; YOU = porous bone; ANT = antler; Rest = no bone items).



Density index calculations

The aim of these indices were to obtain an uniform information about each taphonomic category per unit that enabled us to investigate density variability throughout the whole archaeological deposit. We apply a standardisation procedure to control whether changing quantities are real density variations or correspond to varying excavation unit thicknesses. For that reason three indices were created to calculate quantities in terms of number and weights per 1 cm sub-square unit. We calculate the Density Index (DI) by dividing the number of items in each category from a spit, with its individual spit depth in cm (Z_{spit}) for each sub-square, which in turn is the difference between its top (Z_{top}) and bottom (Z_{bottom}) depth measured in meters. We did the same for the weight (in grams) of each category to get a Weight Density Index (WDI). Finally, we used the Fragments Size Index (FSI) by dividing the weight of each category with its number for comparison with the other categories. The following equations were used:

$$Z_{\text{spit}} = Z_{\text{top}} - Z_{\text{bottom}} \times 100 \qquad (1)$$

$$\text{Density Index (DI)} = \frac{N_{\text{Category}}}{Z_{\text{Spit}}} \qquad (2)$$

$$\text{Weight Density Index (WDI)} = \frac{\text{Weight}_{\text{ Category}}}{Z_{\text{Spit}}} \qquad (3)$$

$$\text{Fragment Size Index (FSI)} = \frac{\text{Weight}_{\text{ Category}}}{N_{\text{Category}}} \qquad (4)$$

For example, in a spit of 3 cm of depth/thickness, every count and weight of that spit was subdivided by a value of 3. By applying the different indices, we obtained a count, weight or size-related value per 0.25 m^2 excavated, corresponding to a cuboid of 50 cm long × 50 cm wide × 1 cm thick, which is taken as representative for that sub-square sub-sample unit.

Spatial distribution analysis

We use spatial analysis that assumes that human space-use within a cave must be accommodated to its structural limitations and, that the overall nature of human occupations remained similar through time (= Palaeolithic hunter-gatherers). For our spatial statistical analysis, we assumed a random distribution of archaeological finds, making the two subsequent hypotheses (H0) our baseline: (1) The Lower Magdalenian horizon (specifically Level 17 in the outer vestibule area) in El Mirón represents a more or less uniform and constant vertical accumulation deposit; (2) The archaeological remains were distributed randomly within the 12 study units addressed here.

The calculated density indices of taphonomic groups provided the basis for spatial analyses and each obtained value is associated to a polygon in a raster resembling the position of the study unit in the outer vestibule of El Mirón cave. GIS-based spatial distribution analyses were performed to identify variations in density vertically and horizontally, referred to as profile plots and distribution maps, respectively. The profile plots provided first insights into density variation throughout the archaeological sequence of the Lower Magdalenian context. We used the cluster method of the ESRI 'Voronoi Map' tool that grouped polygons into five class intervals. The method searches for similarities among neighbouring units allowing the identification of local outliers, coloured grey, and it visualises regions of high vs. low clusters using a colour scale (ESRI identification of local outliers, coloured grey, and it visualises regions of high vs. low clusters using a colour scale (ESRI 2007). In the next step, we created distributions maps based on polygons and used the ArcGIS statistic tool for 'spatial autocorrelation of Moran's I global index' that evaluate whether the pattern expressed among polygons with associated attributes is dispersed, random or clustered. This tool's output refers to the significance on how likely it is that the pattern observed was due to a random chance (ESRI 2009a). After a distribution was identified as no random chance, we used the ESRI cluster and outlier analysis tool 'Anselin Local Moran's I Index'. This results would then evaluate the relationship among neighbouring units, where high *Z*-values indicate that features of similar values building a cluster (of 'hot' or 'cold' spots) and contrary low Z-values indicating high dissimilarities in features between neighbours identifying outliers (ESRI 2009b).

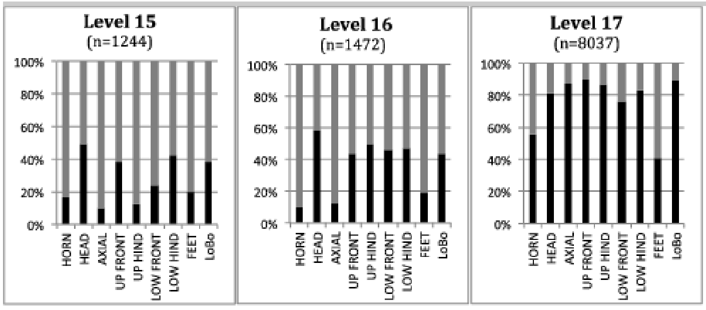
The different, previously calculated index values are expressed in the figures in relation to symbol size, where larger symbols represent the higher values. Additionally, when the Moran's I Index was calculated it is illustrated as thick square outlines for cluster or double line outlines for outlier, both in either red or blue-dotted, for high or low values respectively. Areas with overlap of high DI and WDI values in burnt bones might indicate concentrations of hearth-related activities with high counts and weights. The combination of high DI and low WDI represent areas of higher fragmentation rates that should correspond to lower FSI values. Areas of high FSI indicate large fragment sizes.

Results

Archaeozoology and taphonomy

The percentages of the Numbers of Identified Specimen (%NISP) from Levels 15, 16 and the samples from 17 indicate that the most represented animal in the Lower Magdalenian assemblage is red deer (%NISP~~p~~ = 31.27%) and Spanish ibex (%NISP~~p~~ = 40.40%). Carnivores are scarcely represented in the samples (%NISP~~p~~ = 0.23%). In all levels, ibex always outnumber red deer in NISP, while other ungulates, including bovids (*Bison/Bos*), horse, roe deer, and chamois together comprise 1.29% of the assemblage. Birds, fish, amphibian and rodents make up 0.46%, anatomical identified bones in size classes comprise 24.31% of the individual registered bones and 2.04% are undetermined (compare supplementary information Table S1). NISP from the studied levels increases when including general bag items, especially within the smaller assemblages from Levels 15 and 16. Nearly a third (31.6%) of the individual identified bones from all levels come from general bags. Even within Level 17, with the highest NISP, contribute the identified remains from general bags up to 21%. The surplus of identified bones is remarkable in terms of the high numbers of foot elements. There are also great disparities in the smaller assemblages of Level 15 and 16 in terms of head, axial and long bone parts (Figure 3). The role of carnivores in these Lower Magdalenian deposits seems to have been minimal, as only 127 specimens (1.2% of the studied assemblage) display some traces of wolf-size carnivore activity, such as furrowing, pitting, scoring and puncturing (compare supplementary information Table S2). Half of the bones modified by carnivores were found with digestion marks very similar to what has been identified as stemming from bearded vulture presence at the site (Marín-Arroyo 2010, p. 393–434).

Figure 3. Single piece plotted items (black) and identifiable items from general bags (grey) are shown as NISP counts in percentage by body parts of prey species for each level studied to evaluate volumes contributed from general bags.



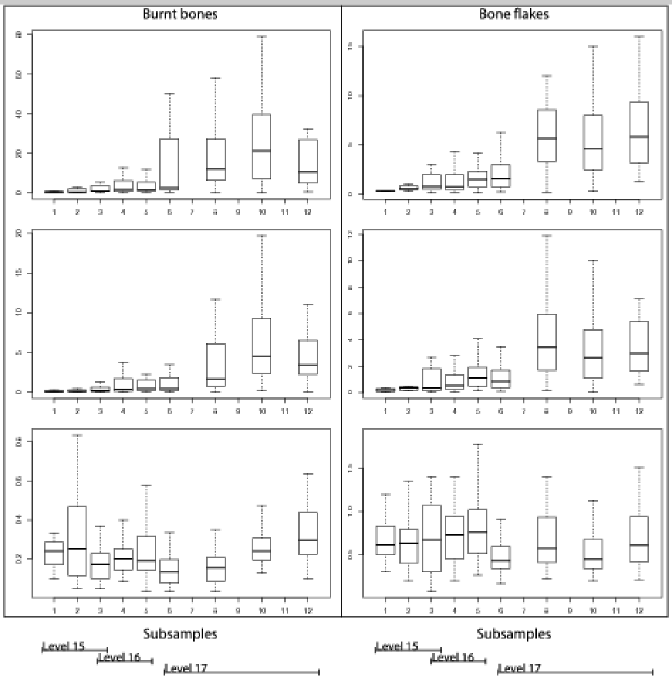
The combined faunal collection from Levels 15, 16 and the sub-samples 6, 8, 10, and 12 of Level 17 include 186.649 bone micro-fragments from general bags, with 13.665 burnt bones and 2.948 bone flakes. All these bone micro-fragments together are useful to understand the general state of preservation and the composition of the archaeozoological assemblage, making their study suitable as a preliminary assessment method during faunal analysis.

Density indices

The DI, WDI and FSI indices calculated from the counts and weights are summarised for the taphonomic categories of burnt bones and bone flakes in Figure 4 as an example. The burnt bone category displays a very high DI mean in Level 17 that increases from sample 12 to 10 and decreases with the transition to the Levels 16 with an already low mean value in sample 6, but showing a high variability. The DI mean of bone flakes in sample 12, 10 and 8 is quite similar, though, already significantly drops within Level 17 between the two sub-samples 8 and 6. Sub-sample 3 is like sub-samples 1 and 2 in terms of burnt bones, but in terms of bone flakes it is similar to sub-samples 4, 5 and 6. A comparable pattern is observed in the WDI for burnt bones and bone flakes, where sub-sample 6 from Level 17 always is more analogous to Level 16 sub-samples. The burnt bones in sample 3 show a mean very similar to those of 1 and 2 when WDIs are compared. The sample 3 bone

The burnt bones in sample 3 show a mean very similar to those of 1 and 2 when WDIs are compared. The sample 3 bone flakes also equal the means of samples 1 and 2, but show more variability in weight. The FSI values show no significant pattern or cluster of higher or lower values through time indicating their variability seems to be better expressed by horizontal spatial statistics.

Figure 4. Boxplots distributions for index values DI, WDI and FSI of burnt bones and bone flakes from general bags by sub-samples under study (outliers excluded).



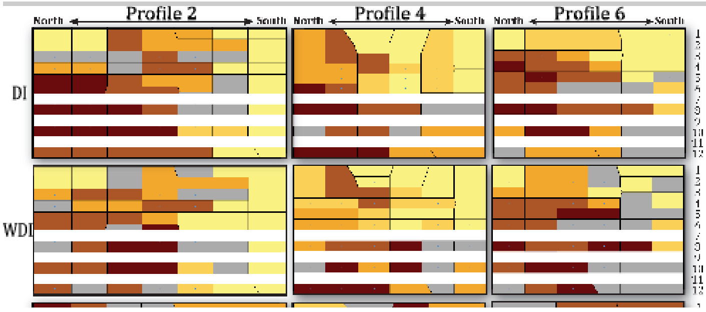
Spatial distribution study

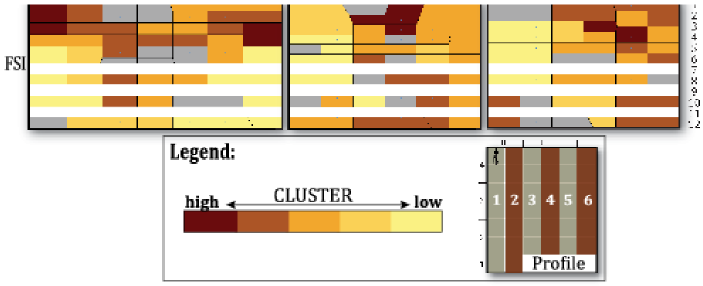
Spatial distribution results are presented in the following paragraphs by profile plots (for Levels 15, 16 and 17) and distribution maps (for Level 17) showing the density analysis for the different taphonomic categories using the DI, WDI, FSI indices. To exemplify how to decipher an archaeological palimpsest with the method, we present the distribution maps focusing on the following criteria: (1) the ‘palimpsest problem’ of Level 17 and (2) the proposed human-made accumulations of burnt bones and bone flakes.

Density profile plots

The results of vertical variability in density of all bone micro-fragments is illustrated with Voronoi maps showing vertically lower study sub-samples have a greater density compared to the upper ones, meaning that generally density decreases with time (Figure 5; compare supplementary information Tables S3, S4 and S5). It is remarkable that a cluster of higher DI values is observable along the northern border of the excavation area, which might have two causes: (1) more bones were deposited closer to the centre of the cave vestibule forming a bone midden-like accumulation and/or (2) bones are more crushed in this area due to intentional cracking or processing, or unintentional trampling. WDI show high values more in the centre of the excavation area. The sub-squares along the southern cave wall show clusters of both low DI and WDI values, indicating that the centres of activity were located at some distance from the cave wall. The higher FSI values cluster mainly in the upper sub-samples of Level 15 and 16, indicating bone fragments of larger sizes within these levels. Higher bone fragmentation was found along the northern border of the excavation area, where FSI values are generally smaller.

Figure 5. Profile plots show density distributions created with the ArcGIS Voronoi map tool using index values DI, WDI and FSI of all bones from general bags. Here is only shown profile 2, 4 and 6.





Density distribution maps

The distribution of all bones micro-fragments indicate by significant *p*-values and the Moran's Index that they are clustered, despite the FSI in Level 17 samples 8 and 12 (Table 1). Burnt bones are clustered in all studied samples, but WDI and FSI in sample 6 and FSI in 10 exhibit no significant *p*-values for spatial statistics. Several *p*-values for bone flakes lie outside the 5% of probability range and these distribution patterns could possibly be explained by random chance; the insignificant values are the DI values for sample 12, the WDI values for sample 8 and the FSI values for sample 6, 8 and 10.

Table 1. The results of the autocorrelation for distribution maps are shown for each sub-sample 6, 8, 10, 12 from Level 17 and the indices DI, AQ9 WDI and FSI.

	All bones			Burnt bones			Bone flakes		
	Sample	Moran's index	*p*-value	Sample	Moran's index	*p*-value	Sample	Moran's index	*p*-value
DI	**6**	**0.59**	**>0.001**	**6**	**0.35**	**0.001**	**6**	**0.43**	**0.001**
	8	**0.30**	**0.002**	**8**	**0.23**	**>0.001**	**8**	**0.68**	**>0.001**
	10	**0.19**	**0.022**	**10**	**0.22**	**0.016**	**10**	**0.22**	**0.028**
	12	**0.27**	**0.007**	**12**	**0.30**	**>0.001**	*12*	*0.12*	*0.256*
WDI	**6**	**0.53**	**>0.001**	*6*	*0.13*	*0.197*	**6**	**0.28**	**0.025**
	8	**0.20**	**0.029**	**8**	**0.23**	**0.001**	*8*	*0.15*	*0.106*
	10	**0.29**	**0.002**	**10**	**0.34**	**0.001**	**10**	**0.27**	**0.010**
	12	**0.50**	**>0.001**	**12**	**0.42**	**>0.001**	**12**	**0.30**	**0.013**
FSI	**6**	**0.20**	**0.052**	*6*	*0.11*	*0.265*	*6*	*0.04*	*0.493*
	8	*0.05*	*0.448*	**8**	**0.33**	**0.003**	*8*	*0.12*	*0.171*
	10	**0.18**	**0.051**	*10*	*0.03*	*0.535*	*10*	*−0.10*	*0.529*
	12	*0.18*	*0.107*	**12**	**0.25**	**0.020**	**12**	**0.26**	**0.040**

Notes: Not statistical significant values show that the spatial pattern can be the results of complete spatial randomness (*italic*~~grey~~ ~~color~~). When a significant spatial patterning was observed *p*-values are lower 0.05 (**bold**~~white~~). Positive Moran's Index values indicate a clustered pattern.

By analysing the distribution of burnt bone fragments we can address questions of hearth location and hearth-related activities (compare Figure 6 (A) and supplementary information Table S6). We summarise every result by sub-sample in the following paragraph. The first distribution map of sample 12 shows an overlap of DI and WDI cluster with high values in the same area, relatively in the middle of the excavation area. Higher concentrations in burnt bones have been found in the H3, I3 and I4; high FSI values indicate larger fragments in the north-eastern part of the excavation. The next sample (10) displays generally higher DI values in most parts of the excavation section, while WDI values follow a semi-circular distribution south and east of square H4. FSI values are dispersed, with two non-significantly clustered, high-density concentrations in the north-eastern and south-eastern corners of the excavation area. Concentrations of burnt bones shift to the eastern border of the excavation area within the next sample (8), while high clusters of DI and WDI are located in square J4. A cluster of larger fragments is identified close to the southern cave wall. The middle part of the excavation contains somewhat higher DI fragments is identified close to the southern cave wall. The middle part of the excavation contains somewhat higher DI values, but comparably low WDI and FSI values indicating small fragments in higher quantities. The last, uppermost sample (6) in Level 17 shows a concentration of high DI values of burnt bones along the northern excavation border, with generally low WDI values. Some higher FSI values seem to be aligned in a diagonal zone, ranging from around square H4~~3~~ to J2, but WDI and FSI values are not significantly clustered.

Figure 6. Distribution maps showing density index values DI, WDI and FSI of burnt bones (A) and bone flakes (B) for Level 17 samples 6, 8, 10, 12. Symbols: Black dot sizes are relative to their index value with highest values representing larger bubbles. Each index follows its own scale. Thick squares = cluster, thin double outlined squares = outliers, red = high, blue dotted = low.

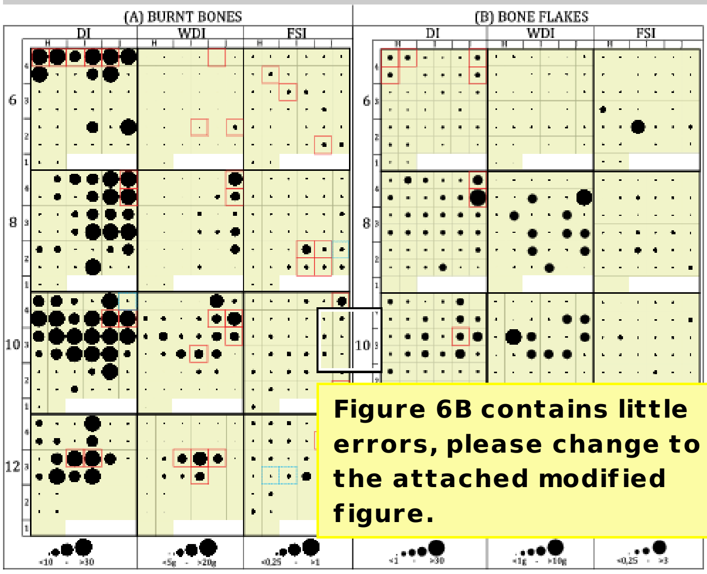


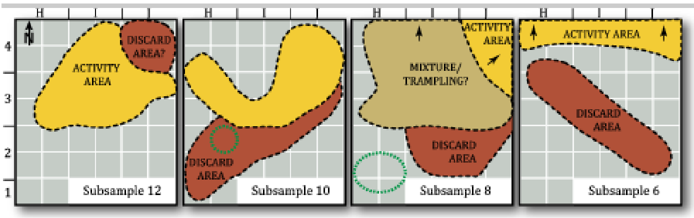
Figure 6B contains little errors, please change to the attached modified figure.

When we analysed the distribution of bone flakes, which result from bone-cracking activities, we counted the amounts of only obvious bone flakes for each spit (compare Figure 6 (B) and supplementary information Table S7). The first distribution map from the lowest sample (12) shows somewhat higher concentrations of DI and WDI values for bone flakes in squares I3 and J3, but DI values show no significantly clustered pattern. ~~L~~A cluster of larger fragments ~~seem to be~~ is located in the north-eastern corner. In sample 10, there is a high cluster of DI values located in J3 and J4, but values seem to be more dispersed. H3-B shows a comparable high value in WDI and FSI of bone flakes. The overlying sample 8 shows an overlap of high DI and WDI values in J4 and some bigger pieces close to the southern cave wall. The uppermost study sample (6) in Level 17 displays higher DI and WDI values along the northern excavation border, while FSI values are randomly distributed. Some bigger bone flakes are found in the southwest of the excavation section.

Identification of activity areas

The archaeological remains indicate that a broad spectrum of activities was performed within the outer vestibule at El Mirón cave, including activity areas for burning, meat-, marrow- and grease-processing, and next to those activities, it was also used as a discard zone. We can summarise our results from the bone micro-fragment density analysis from bottom to top as it follows (compare Figure 7): The oldest occupation in this analysis is sample 12 from the base of Level 17, where the excavation uncovered remains of diverse activities in the middle area of the trench. Activities in this sample appear very spatially limited or localised.

Figure 7. The reconstruction of activity areas is based on the data obtained from density analysis and the location of high cluster, here focusing on burnt bones and bone flakes from the sub-samples 6, 8, 10, and 12. Areas are subdivided into possible activity or discard areas and trampling zones. Dotted circles mark suggested hearth locations from previous studies on fire-cracked rocks (Nakazawa 2007; Nakazawa et al. 2009).



With the next sample (10), activities shifted into a semi-circular arrangement with lower densities of anthropogenically modified faunal materials in the middle, which are similar to a hearth-centred model (Binford 1978b). In the centre of the modified faunal materials in the middle, which are similar to a hearth centred-model (Binford 1978b). In the centre of the area there might have been a working/cooking place, including bone grease rendering using the stone boiling technique as suggested by other archaeological finds at the site (Nakazawa 2007; Nakazawa et al. 2009).

The next higher sample (8) shows a concentration of bone-cracking activities and burnt bones in the north-eastern corner of the excavation area, again with a possible discard zone including larger fragments along the southern cave wall. It is in this marginal zone where previous analysis of fire-cracked stones by Nakazawa et al. (2009) suggested the existence of another hearth location. Another large area extending from the middle to the northern border, in the zone of most activity, is characterised by high fragmentation rates that might indicate trampling action. The centre of fauna-related activities might have shifted 'outside' of the excavation area to the north-east, i.e. toward the centre of the inner vestibule.

The uppermost sample (6) in Level 17 yields its highest concentration of DI values along the northern excavation border and the larger fragments that are aligned diagonally within the area might indicate a discard zone.

In summary, we have seen that a former, quite localised activity area may have changed into the segregated use of space similar to what would be a hearth centred-model based on anthropogenically modified bones. This central area was not identified as a hearth during excavations, but might represent a cooking place, as small burnt bone fragments and bone flakes are grouped here and hot stone cooking is suggested for Level 17, since abundant fire-cracked rocks have been identified (Nakazawa 2007). With continuous occupation of this location, the centre of carcass-related activities seems to shift to the north-eastern border of the excavation area, further inside the cave, leaving evidence of a possible trampling zone, indicated by a high number of smaller fragments in the middle of the area. The uppermost sample 6 of Level 17 shows a high concentration of activities at the northern border; it is probable that they represent the last traces of Level 17 activities, while spatial distributions seem similar to those of Level 16 materials in terms of density. These results might indicate another shift of activities and site use towards the centre of the cave vestibule, north of the excavation area.

Discussion

Methodologically, one of the most important steps for density analysis is to provide a comparable data-set through the definition of indices that standardises find density and refers to the same amounts of sediments excavated. The DI-density index based on the number of specimens represented in each taphonomic group seems to be a very appropriate value with which to identify spatial clusters. The WDI values seem to be equally useful for accessing density variability data and to reveal spatial patterns. In cases of low-density occupations, the FSI seems to be a stronger value, although, it is more of a supplementary index used in combination with the two above-described ones for reconstructing spatial patterning. The method is a rather easy one when only using weight and WDI calculation for density analysis, especially by saving time that would be needed to count the bone micro-fragments. The WDI index is stronger when combined with the FSI, whose calculation is in turn based on both counts and weights. DI on its own seems to be also a strong value, but it depends on the degree of fragmentation on the bone assemblage. Voronoi Maps have been found to yield easy-to read visual output with ArcGIS software, even if they are 'exploratory' tools. The statistically significant output given by the spatial statistic tools using Moran's method is shown as suitable for the questions posed here, as the method locates clusters of both high and low values.

The results of this study highlight the value of bone micro-fragments in faunal studies, which are normally less than 5 cm in size and sometimes weigh less than 1 g. But if these micro-fragments are not considered in macrofaunal analyses, valuable information is undoubtedly lost. During the analysis of general bags, usually more identifiable items are found, especially the smaller skeletal bones, as well as tiny pieces of worked bones. Both large and small items contribute to our understanding of subsistence behaviour. Therefore, this study shows that skeletal representation changes drastically and the interpretation on the faunal assemblages differs when micro-fragment data are included. Bone micro-fragments are normally neither taxonomically nor anatomically identifiable, but bone flake densities can be compared to bones with impact marks for detecting bone-cracking work areas, for example (Geiling et al. 2016). It is in the nature of burnt bones to be heavily fragmented and thus small (Shipman et al. 1984; Costamagno et al. 1999, 2005, 2009; Théry-Parisot et al. 2005), making them relatively rare among individually recorded remains, a circumstance that can lead to an incomplete faunal record if they are not taken into consideration. The degree of fragmentation of small, intentionally broken bones might proceed even further with intensive human occupations and thus trampling activity (Miller et al. 2009). Especially small bone micro-fragments can display one of the ultimate end-products of a *chaîne opératoire* of animal carcass exploitation (Théry-Parisot et al. 2005) that might include all the activities of hunting, dismembering, defleshing, marrow bone cracking, cooking, burning and, finally, trampling. After all, bone micro-fragments originated from larger bone pieces and thus from complete anatomical elements of animals that were hunted and transported by past hunter-gatherers.

This study focused on micro-fragments as a resource of additional information for deciphering archaeological palimpsests. With the analysis of palimpsest deposits, we can access information on various levels (Binford 1981; Bailey and Galanidou 2009). We understand human behaviour better when combining both, whole time-averaged palimpsests and the dissection thereof into finer (albeit more or less arbitrary) sub-units that come closer to single-event timespans. Observation of long-term trends within the context of this paper, gives us more information on the massive palimpsests that existed in many Lower Magdalenian settlements in northern Spain. These kinds of deposits especially characterise that specific period in the Cantabrian region, but we poorly understand what caused them to emerge or eventually to decline. Furthermore, we have no idea as to how these occupations were related to other variables or causal factors such as environment, demography, social relationships, etc. We should remark that these long-term trend interpretations often originated from the nature of excavation practices. Old excavated materials frequently leave researchers with no choice but to lump archaeological information from many different living floors together, because finds had not been anywhere close to meaningfully subdivided during excavation (spectacularly the case, for example with Obermaier's 2 m-thick Lower Magdalenian horizon in El Castillo), as compared to modern excavations done by spits of only a few cm in thickness, with meticulously recorded depths, single-piece plotting and fine-mesh screening (Straus 2008). Palimpsests are the most usual records and will remain time-averaged deposits that researchers need to untangle if/when they are willing to try to understand the processes that led to their formation and abandonment. One workable way to access this information seems to be to decipher a palimpsest by creating sub-samples of defined sizes for comparing them such as to at least come close to approaching single events as it is shown here in this study. Find density variability seems to be one suitable method with which to access information on variation within palimpsests, especially when concentrations of bone micro-fragments sorted into taphonomic categories can be used to test for variability in space and time. When summarising our results, we might reject our first hypothesis H0-1 that the Lower Magdalenian level in El Mirón had a uniform and constant accumulation history, because density varied though time and space as exhibited by the test of the global and local Moran's Index for profile plots and distribution maps. The results of local cluster and outlier analyses identified different clusters off both high and low density within the profiles, as well as in the distribution maps. With these outcomes, we were also able to reject our second hypothesis H0-2.

The results show, contrarily to the previously suggested central hearth position in Level 17 indicated by charcoal flakes and fire-cracked rocks (Nakazawa et al. 2009), that the central role was taken presumably from the cooking activity itself, but not from the hearth. The hearth is the feature involved in the cooking process. Bone cracking and small superficial hearths that contain fire-cracked rocks seem to be located around and near that centre of activity, comparable to what was observed in a study of a prehistoric Indian village (Karr et al. 2015).

We can summarise for the case of El Mirón Cave that, when included, taphonomically categorised bone micro-fragments can provided additional chronological information that did not exist before this detailed study of the occupational history. We have seen that this kind of analysis might be an easily replicable, efficient method for deciphering palimpsest deposits that in turn can reveal important insights into past hunter-gatherer lifestyle changes.

But why would different activities have shifted across space within the cave and through time? The high density of human occupation that is reflected by this palimpsest assemblage suggests either a long-term or very frequent use of this cave site during the centuries-long deposition of Level 17. The initial occupation changed from having more localised activities to a certain elaboration of site structure that possibly involved more people, including multi-generational social groups who operated in at least this area of the cave. Longer occupations by larger groups are likely to have more intensively exploited local resources, including meat, marrow and grease usage. Certainly shifts in activities to other areas in the cave during its Lower Magdalenian occupation can be intuited. A possible demographic reason could be that fewer people occupied the cave site, and so used smaller or other parts thereof. Given the fixed aspects of shelter, light and water drip areas in the cave, other aspects might have influenced the segregated use of space within El Mirón cave. Seasonal or climatic temperature changes or the location and intensity of water drips from the cave ceiling might have influenced the displacement of activities further inside or outside the cave. More light could be shed on this issue using further multidisciplinary analysis that include detailed taphonomic analyses and environmental reconstructions.

Conclusions

We conclude that the taphonomic and zooarchaeological results are extremely valuable and researchers are prone to lose additional information if the study of bone micro-fragments, normally originating from extant collection, is not dealt with accordingly. Bone micro-fragments represent parts of the *chaîne opératoire* of animal carcass exploitation, thus improving our human behaviour analysis through the reconstruction of activities, the segregated use of space and shifting site use. Here we also used these bone micro-fragments to dissect and decipher aspects of the Lower Magdalenian horizon in the outer vestibule area at El Mirón cave, which is commonly described as a massive palimpsest of human occupation. This method allowed us to observe variability by thin slices of sediments representing shorter periods of time than the usual interpretations by whole archaeological levels. With the results obtained here, it was possible to reject our initial hypothesis that vertical and horizontal distributions within this palimpsest were the results of random chance.

A successive intensification of site use was observed within Level 17. Very localised activities have been identified at the 'beginning' of this palimpsest accumulation (lower Level 17) that progressively were arranged into a more structured pattern of site-use with a presumed cooking area as one of its centres. Cooking activities including grease rendering are suggested, due to the high fragmentation of the bones associated with fire-cracked rocks found within this level (Nakazawa 2007). This activity area, however, shifted, with further occupation eastward towards the inner part of the cave vestibule and faunal remains seem to be more mixed, possibly through trampling. At the end (top) of Level 17, the intensity of the occupation in remains seem to be more mixed, possibly through trampling. At the end (top) of Level 17, the intensity of the occupation in this area of the cave dropped off drastically, but nevertheless seems to have persisted for some time, though in a different manner, possibly with its centre elsewhere in the cave. Levels 15 and 16 mark the beginning of a time of decreased use or even long-term abandonment of the site by late Lower Magdalenian occupants. Possibly shorter or less frequent site use episodes nonetheless display a distribution pattern similar to that of Level 17, with a possible cooking zone surrounded by bone cracking activities perhaps centred east of the excavated area.

Disclosure statement

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Supplemental data

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